

Construction of an Analog Educational Game: Exploring Card Game Mechanics to Create an Astronomy Game for Fourth and Fifth Graders



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INTRODUCTION

Scientific innovation is at the core of nearly every facet of our day-to-day lives. Someone had to invent the phones we carry, the car that provides us (relatively) quick transport to work, the computer that keeps us occupied, the TV that we watch, and the video game systems we play. Inventions brought to us by the scientific community, in other words, present themselves in innumerable everyday ways in our personal lives. Not surprisingly, then, science, specifically engineering, serves as a significant portion of the job market. The strength of the scientific community is important to the wellbeing of each and every citizen and important to the wellbeing of the global economy. Unfortunately, the United States' scientific contributions to the world are in a steady decline. "Fewer than 15 percent of current US college undergraduates are pursuing degrees in science or engineering - compared to more than 30 percent in India and more than 40 percent in China" (Microsoft).

WHY FOCUS ON STEM?

In 1993, the United States established the National Science and Technology Council (NSTC). As part of NSTC, the Committee on STEM Education (CoSTEM), coordinates educational activities focused on the study of Science, Technology, Engineering and Mathematics. In 2010, the government announced the America COMPETES Act, which aims to build an "innovation economy for the 21st century - and economy that harnesses the scientific and technological ingenuity that has long been at the core of America's prosperity and applies that creative force to some of the biggest challenges we face today." CoSTEM focuses on policy and research surrounding STEM education from Pre-K to lifelong learning, as well as workforce trends and needs. "Children only have one chance for an education. And the youth who are in school now need a better education today if they are to thrive and succeed tomorrow. Ensuring that our nation's children are excelling in the STEM field is essential" (STEM LabReport).

Why is STEM important? In 2007, the US Department of Labor, Employment and Training Administration, reported that 61 percent of opinion leaders, and 40 percent of the general public identify math, science, and technology skills as the most important ingredients in the nation's strategy to compete in the global economy" (DOLETA). The report was riddled with warnings that the US is quickly falling behind on a global scale. The report specifically points out that if something

doesn't change, 90 percent of the scientists and engineers in the world will be located in Asia. Keeping that in mind, we would do well to heed National Science Foundation's reminder that approximately 50 percent of all economic growth in the US can be attributed to scientific innovation (RocketMavericks). "Clearly we need a cultural transformation to make science and technology a field that everybody wants to get into" (STEMLabReport).

"STEM education matters to average citizens as much as it does to workers in technical fields... The tremendous rate of technological change and globalization has increased the need for the electorate to keep current on multiple, complex topics" (Illinois). Looking at the issue from the US as a whole, it is estimated that out of the fastest growing careers for the next 10 years, 15 of them rely heavily on an in-depth foundation of science and mathematics. Student test scores from 2010 painted a bleak picture of current STEM education in the US. According to the International Society of Automation, mathematics tests taken last year by eighth graders worldwide revealed that the US is currently lagging behind 14 other countries including: Singapore, Republic of Korea, Hong Kong SAR, Chinese Taipei, Japan, Belgium, Netherlands, Estonia, Hungary, Malaysia, Latvia, Russian Federation, Slovak Republic, and Australia. And eighth graders aren't the only ones who are underprepared; the 2010 ACT showed that only 29% of students tested in 2010 are considered college-ready in science and 43% are considered college-ready in math (ISA).

More often than not, from birth, children are intrigued by the world around them - avid explorers and problem solvers. Somewhere along the way, they risk losing their interest in the world around them. "Research documents that by the time students reach fourth grade, a third of boys and girls have lost an interest in science. By eighth grade, almost 50 percent have lost interest or deemed it irrelevant to their education or future plans. (US News)" According to STEM Lab Report, children with recurring troubles in mathematics are less likely to graduate from high school or attend college. On the same token, "Early math skills are more predictive of later reading achievement than early reading achievement itself. In short, those who start ahead, stay ahead" (STEMLabReport).

Effective education is essential to keeping student interested in STEM topics from an early age. In order to keep students interested, there has been a rather heavy push to introduce STEM focused games in homes and classrooms. As part of a Microsoft/Time Warner cable public service announcement for Kinect, Time Warner's Tessie Topol stated, "We want to remind kids and their parents that many of the things they consider cool require a background in STEM...you can't build a flying car...and you can't be on the team that is creating the coolest and most advanced video game ever if you don't study math and computer science" (GamePolitics).

WHY GAMES?

As addressed in a variety of game studies, our society often strikes a harsh divide between work/education and play. Within the last few years, there has been serious move towards bringing game mechanics and a sense of play to nearly everything we do including, but not limited to, work, driving, eating, exercising, and most importantly - education. Games can play a huge role in supporting teachers and students in the classroom. Unlike traditional classroom tools, a game can support students as they learn the ins and outs of game mechanics. "Time has come to revisit the almost alarmingly simple, yet powerful construct of play and to legitimize play's role in the field of instructional technology" (Rieber).

As Reiber explains in *Seriously Considering Play*, imitation and play are two things which children are experts at. Not only that, but many games also require the use of problem-solving and critical thinking skills, which children are constantly practicing in school, sports, and life at home.

The push for educational reform in the U.S. is strong. Currently, the dominant educational paradigm is "didactic instruction," where learning is viewed as an information transmission process: teachers have the information, students don't, and teachers' lectures serve to move information into the heads of students. In contrast, national and state education reform movements are advocating for students to be actively engaged in learning, constructing understanding and meaning, not receiving it (*Learning Theory in Practice*).

According to STEM Lab Report, "When it comes to science, very young children - naturally inquisitive learners who ask an average of 76 questions an hour - bring surprising abstract abilities to the task of learning." The one method that is found to work best from Pre-K to lifelong learning is to learn by doing. One example of being able to measure abstract uses of mathematics is through the use of board games. Board, card, and video games "combine visual, spatial, kinesthetic, auditory, and temporal clues about counting and the relative values of numbers. Children also strongly benefit from 'math talk' and mathematizing - converting formal and intuitive knowledge into formal and organized ways of thinking and representation" (STEMLabReport).

"Educational games are very important in the classroom, no matter what the age of the students" (Helium). Recent generations of students have been raised on games for their entire lives. Some students eat, sleep, and breathe games.

The idea that children learn best by constructing ideas and knowledge through activity alongside others has a rich history in educational research and theory. Broadly speaking, this notion of 'learning-as-constructing knowledge' emphasises how children's development takes place through participation in a social world and interaction with people, events and objects. For some games and learning enthusiasts, games are viewed as ideal platforms for

trying out ideas, making decisions, communicating with others, and of exploring or making new worlds.

According to this perspective, through the act of playing games, players are active in the construction of knowledge, rather than its passive recipients. This view therefore reinforces the notion of schools and classrooms as spaces for experimentation and focuses on the ways in which people learn by constructing knowledge actively alongside others, rather than by receiving knowledge passively from others, namely teachers. These kinds of activities are characterized by spaces to explore, room for learning through both success and failure, feedback that learners can use to adjust their own understanding, and multiple possible outcomes. They often take the form of problems that learners are motivated to solve in unique and active ways²¹ (Futurelab).

Because of this, games can and should be used as supplemental material in any curriculum - they are engaging, fun, and can build upon lessons that are already being taught in schools.

OUR PROJECT

Based on these facts about education and learning, we began our study with the following questions: "How best can we fill a need in either science or math curriculums to help educate children using games? Was there an area that stood out as needing intervention?" We researched many math and science games, as well as puzzles, available in both analog and digital forms. We sought out teachers of varying grades and asked them where they saw learning gaps for children in their classrooms. Overwhelmingly among the elementary teachers we spoke with, it was in the field of science. More specifically, and perhaps surprisingly, they asked for something that focused on astronomy.

A recent radio interview with Neil deGrasse Tyson further piqued an interest in creating a game for astrophysics. Dr. Tyson is an astrophysicist who is the director of the Hayden Planetarium, host of NOVA ScienceNow and StarTalk, author of several books and was appointed by President Bush in 2004 to serve on a 9-member commission to assess the Implementation of the United States Space Exploration Policy. Tyson is an outspoken supporter of the US Space Program. During a KUOW "Weekday" interview, host Steve Scher posed a question sent in by a listener.

Steve Scher: Rachel writes – "I think it's unfortunate that the focus on improving interest in science seems to be focused exclusively on astronomy and planetary sciences... Although these fields are interesting and important there are urgent pressing needs in science that aren't being met: climate change, global water shortage, species loss are immediate areas of

inquiry that need to be addressed and sending people to the moon or Mars does little to address these questions or advance the fields. I would be interested in how Dr. Neil deGrasse Tyson would improve recruitment to all sciences rather than simply throwing money at NASA."

Dr. Tyson: ... You should know, first of all, that beginning in the 1990s, the portfolio of research that goes on at NASA actually touches all the major branches of science. So, of course it touches astrophysics, but it also touches Biology and the search for life in the water rich areas of the solar system and elsewhere. It involves Chemistry- trying to understand the soils of the planets or the "regolith" as it is called, on the planetary surfaces we visit. It involves Geology, but we don't have a word for that – so "planetology", 'Geo' means 'Earth' –so "planetary geology" the geology of other planets all these fields, as well as Engineering- Aerospace Engineering, Mechanical Engineering. All scientific frontiers are part of the NASA portfolio. So, to fund space exploration is tantamount to funding exciting moving frontiers in all of these fields that you spoke of, that's first.

Second, our understanding of global climate phenomenon owes its origins to the study of not only asteroid impacts on Earth but also what was going on, on Venus. Venus has a global planet wide greenhouse effect. It is 900 degrees F. That is a planet gone "bad." And it's kind of useful to know what happened there so that we get some sense of what is happening here on Earth.

The fact that the dinosaurs all went extinct everywhere in the world at a time that Earth was struck by an asteroid that hit in one spot in the world is what birthed an entire new branch of climate study which involves global climate change from local phenomenon. And so, insights into Earth are maximally achieved by looking at other examples that exist around us. You cannot know all there is to know about something only by studying that object. At some point you need to compare it, and this is what we call "Comparative Planetology."

That is one aspect of this, but I think a more important aspect of it is: Kids growing up, they're not necessarily thinking about saving the world, they are just curious about the unknown. And, if you want to attract the best students in an educational pipeline then you want to give them the coolest things to work on. You cannot force someone to say, "We have this problem in society - I need you to fix it." No! You say, "Here are some really cool problems to work on, "Oh! I want to BE a chemist. I want to BE an astrophysicist. I want to BE an aerospace engineer. I want to BE the geologist!" Now you have an excited pipeline of students who want to actually apply this knowledge. It is the cross pollination of knowledge that is responsible, history has shown, that is responsible for revolutionary

advances in our understanding of the world

(<http://www.kuow.washington.edu/program.php?id=23359> min 36:57-40:37).

According to Grace Dublin, a 4th and 5th grade teacher in the Seattle Public Schools, children take standardized tests in 5th grade that ask astronomy related questions, *but there is no astronomy included in the science curriculum for the 4th and 5th graders.* Additionally, she recounted how some of her students did not understand that the Earth rotated on an axis and others had a variety of misconceptions about the physics of space. Another 5th grade teacher in a private Seattle school told us that he develops his own astrophysics curriculum; there is no established curriculum for him to follow.

Our curiosity about how games might be used as an adjunct vehicle for science education set us on a path to create a game for 4th and 5th grade students that introduces fundamental language and ideas of our solar system and some foundational ideas about planetary systems.

According to the Washington State Science Standards, 4th and 5th graders need to learn the following concepts:

EALR 4: Big Idea - Core Content: Earth and Space Science Earth in Space (ES1) Earth in Space

In prior grades students learned that observing and recording the position and appearance of objects in the sky make it possible to discover patterns of motion. In grades 4-5 students learn the full implications of the spherical-Earth concept and Earth's place in the Solar System. The upper elementary years are an excellent time for study of the Earth in space because students have the intellectual capacity to grasp the spherical-Earth concept and the relationship between the Earth and Sun. This major set of concepts is a stepping-stone to a later understanding of all concepts in astronomy and space science and an essential element to further understanding of how the Earth and other planets formed.

Content Standards - Performance Expectations; 4-5 ES1A; 4-5 ES1B 4-5 ES1C; 4-5 ES1D

Students know that: Earth is approximately spherical in shape. Things on or near the Earth are pulled toward Earth's center by the force of gravity. Earth's daily spin relative to the Sun causes night and day. Earth's nearly circular yearly orbit around the Sun causes us to see different constellations at different times of year. The Sun is a star. It is the central and largest body in our Solar System. The Sun appears much brighter and larger in the sky than other stars because it is many thousands of times closer to Earth.

Students are expected to: Give evidence to support the idea that Earth is spherical in shape (e.g., research Earth images from space, shape of Earth's shadow on the Moon during an eclipse of the Moon). Draw how objects would fall when dropped from various places around Earth, demonstrating that all things fall —downll toward Earth's center. Use a physical model or diagram to show that Earth's spin causes night and day. Use a physical model or diagram to show how the different constellations are visible in different seasons, as a consequence of Earth orbiting the sun. Identify that our Solar System contains only one star, the Sun. Explain that the Sun appears brighter and larger than any other star because it is very close to us (K12 WA Standards).

Yet a search of Science Curriculum on the Seattle Public School website revealed no units that covered Earth and Space. The site states, "The following have been adopted for Seattle Public Schools and are provided to support elementary science instruction. All units have been aligned with [Washington state standards](#) (GLEs and EALRs) and to meet teacher needs." So the discrepancy is unexplained (Seattle Schools).

Additionally we conducted a search of games on a variety of websites dedicated to teaching astronomy to children. There we found word puzzles and quizzes, but no games with actual game mechanics. We decided that though the Washington State Science Standards only required very basic understanding of concepts, that we would introduce more concepts into our game in order to lay a foundation of language and idea for future study. We also decided that we would integrate knowledge of astrophysical relationships, particularly in our native solar system, into the game mechanics themselves.

We decided for our first game to develop an analog version. This strategy enabled us to think through mechanics that would fulfill the learning requirement, provide fun, and be age appropriate. We see the exercise of creating an analog game as an important antecedent to digital design, and an option that merits consideration before investing time and money into the creation of a video game.

Our first step was to brainstorm about various mechanics to employ. We were somewhat limited in the mechanics because we chose a young target audience. We finally settled upon a rummy style game collecting sets. The initial design of card deck included eight planets with 6 attributes and a sun card and moon card that were wild cards. Players could collect either planets or attributes to earn points. Written on each card were facts about the planet to introduce players to the various concepts we were introducing. Points were scored with cards that were laid down and bonus points given to the player to play all their cards in their hand. Players who did not play all their cards had any cards left in their hand count as points against them in totaling their points.

INITIAL PLAYTEST SESSION

We then had an early play test of the game. The game went quickly and was fun as a card game, but we found that there was little interaction with the information about the solar system and subsequently little learning about the topic. Additionally, we did not like that the cards were limited to the solar system. We wanted to expand the thinking and knowledge beyond models that already existed and again introduce players to concepts and vocabulary that they might encounter in the future.

So we added a group of "other" cards that included black holes, comets, space junk, asteroid belt, binary star systems etc. to expand the thinking beyond our solar system. Also, to prolong the game, we added the mechanic of being able to "buy" cards. This increased playtime, interaction with more cards and allowed players to gather more points per hand. We increased the number of points required to win in response. We also began thinking about mechanics to increase interaction with the cards. We considered a quiz or trivia mechanic, and then made a rule that players had to read their cards when they laid them down.

SECOND PLAYTEST SESSION

We revised the cards and conducted a second play test using the new mechanics. The buying mechanic was very helpful in extending game play and creating more intrigue in the game. The tension between getting more points for laying down more cards and being left with several cards in their hand that detracted points created an interesting dichotomy. The mechanic of reading cards allowed as they were played simply felt like drudgery and not really fun at all. Additionally, the facts weren't really remembered, just stated. We also tinkered with how many cards should be dealt, and how many cards were required to create a set. Additionally we worked on the graphics of the game. We looked at different ways the graphics could support the play. We attached color to the various planets as well as letters to denote which planet and pictures to denote the varying attributes. The color and graphic coordination greatly enhanced playability.

After the second play test, we decided that none of our mechanics were really addressing the 'educational' piece of the game. We decided to create action cards that affect the play of the game and might require players to compare the various cards that are in play or in their hand. Thus the players would compare and contrast the various attributes of the cards and subsequently learn the facts and concepts that the cards relay. Additionally this mechanic encourages interaction between players and the discussion of concepts and information.

We also made the decision to remove the set of cards in the deck that denoted bodies outside the solar system and instead used them as action cards. The cards are now used as a learning mechanic and the terminology (i.e. binary solar system) is now used to familiarize the player with the terms rather than teach the phenomenon itself. We did have many cards that one player could use to disrupt the play of another player. We decided to remove this mechanic, however, concerned that players might use the mechanic against an individual player and subsequently lead to unfair or unkind treatment. We wanted to limit the possibility of bullying or targeting any individual player. Though the game does have some strategy involved, we use luck as a large mechanic to level the playing field for young players and keep the odds relatively even among all players.

THIRD PLAYTEST SESSION

During our next play test, we really explored how the action cards might work. We encountered several problems during this particular test. How the action cards were to be integrated into the rummy setting became very confusing. We realized that we needed to have clear rules around where they were placed and how any scoring occurred with them. Additionally, we had to make decisions as to whether the card itself was worth points or whether it was only worth points if played in conjunction with another card. The scoring became really complicated and we knew it needed to be simple for the age group. Also, many of the action cards weren't applied until cards were actually counted. This set up a potentially difficult situation with 9 and 10-year olds arguing about points at the moment of counting. We thought this would create a lot of strife. We decided that each action card would be added to the player's score the moment they got the card. If there was a card that could be played with it, they got that point only if they played the card by the end of the round. We also assigned each of the cards either 0 points or 1 point so that there was no doubt how the card should be scored. We also eliminated any negative scoring cards. We thought it might be frustrating for players to get a 'negative' card when we really want to encourage interaction with the cards.

We made revisions to the deck and action cards and once again held a play test. With more rules clearly defined and a 'working' model of the game, we had 4th graders play the game on their own (no adults included). We did explain the rules to them with the assumption that a teacher would most likely read the rules and explain the game if used in a classroom setting. We had many findings during this particular play test. Some of the children were very familiar with concepts such as 'revolution' or 'rotation'. Other children were not familiar with the concepts at all. We concluded that we needed to add a 'definitions' card that each player would have next to them that would define the concepts. This would add to learning and allow the children to discover the meanings rather than rely upon the knowledge of the teacher.

The children also found some of the rules on the action cards difficult to understand. For instance, the 'Solar Wind' card gave an extra point to the card that had little or no atmosphere. One child pointed out that he had a 'moon' card and it was of a moon that had an almost non-existent atmosphere. We needed to clarify that the action card applied to a planet that had little or no atmosphere.

The children also asked how many 'buys' they could make. We decided to give them 'unlimited buys' to see what happened. The children then employed a strategy of buying as many cards as they could to make sets and subsequently get as many points as they could. Since there was no penalty for having cards left in your hand, the strategy made perfect sense. The children played a single hand joyfully for 45 minutes collecting as many points as possible! We decided to limit each player to 3 buys in order to speed up game play.

The children chatted excitedly about the game after the testing was completed. One child confessed that he felt like he didn't know as much as the other kids. He thought a 'definitions' card would be very helpful.

The next day, one of the children asked if we had a new version of the game ready. He wanted to play again. He said it was really fun!

FOURTH PLAYTEST SESSION

Although we wanted to keep our play tests focused on the target age group for the most part, we tested several times with adults. At a recent game night with colleagues from the MCDM program we played our game in a larger group than we had tested previously. We tried the game with four people. For the most part, the game went very smoothly. The only real criticism that we received was that buying cards should come at a cost. In our current version, we stripped out many of the negative aspects of the game such as receiving a penalty for buying cards or for having cards in your hand at the end. For adult games, we feel that it makes sense to penalize people and add mechanics where people are able to screw around with each other's points or cards. For this game, since it is tailored for a much younger audience, we felt that it was best to keep the game positive. In the future, we do think we could try adding back in a penalty to see how it affects play.

CONCLUSION

Overall, we think that our project was a success, but just the first stage in our development of games. We would like to continue to play test our analog game, especially in larger groups of

elementary students. We would also like to conduct a controlled research experiment to be able to test the effectiveness of our game at educating students, relative to students with no exposure to the game. If all goes well, we would then explore several options: refine the game and publish it, consider alternate topics for a game with similar mechanics, and/or incorporate some of the game components or dynamics into a video game aimed at a slightly older demographic of students.

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