International Journal *of* Designs for Learning
2021 | Volume 12, Issue 1 | Pages 1-15

AT PLAY IN THE COSMOS

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At Play in the Cosmos is a game for University-level Astronomy courses. Designed as a collaboration between the Games + Learning + Society Center, an academic center at the University of Wisconsin-Madison, and Norton & Company, Cosmos is intended to support a "game-first" model of curriculum in which students play the game before engaging in other activities. Cosmos includes about 4 hours of game play and spans the entirety of course. It includes over 25 embedded simulations that are also used for homework, lectures, and demonstrations. The design process and resulting artifact was colored by institutional constraints, specifically a lengthy pre-production that demanded extensive documentation. The subsequent development process followed a relatively linear, waterfall process and resulted in linear game. Designers attempted to mediate this linearity through a crafting system that enabled players to explore the Universe and mine celestial bodies for resources. As a game intended to compete in the market, Cosmos included a relatively high production quality led by a team experienced in AAA development processes, and the chapter focuses on the development of art styles, interfaces, and fitting voice overs in on a constrained budget and timeline.

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https://doi.org/10.14434/ijdl.v12i1.31262

INTRODUCTION

In the summer of 2017, the Academic Publisher W. W. Norton & Co. and Gear Games at the University of Wisconsin-Madison co-published *At Play at the Cosmos* to tens of thousands of students through WWNorton.com and the iTunes store. A "game-first" model for collegiate undergraduate courses was the topmost frame and driving perspective behind this game. Secondarily, it shares insights in academic-industry partnerships to build games. This design case focuses on two key design considerations: (1) creating gameplay experiences to produce specific learning outcomes without losing a sense of play, and (2) linking qualitative and quantitative Astronomy understandings through gameplay.

INSTITUTIONAL CONTEXT AND BACKDROP

Gear Learning / Games + Learning + Society

Gear Learning is a research and development center at the University of Wisconsin-Madison that grew from the Games + Learning Society (GLS) Program. GLS formed Gear to be an on-campus research and development team for students and professors to work with developers in a skunkworks environment. We assembled a team of 12 graduate students, two post-docs and staff of 15 full-time game developers with 100+ years combined commercial experience, funded through a variety of traditional University grant-funded projects, including sub-awards on other researchers' grants. We hoped that this team could produce innovations that overcome the "valley of death" (the point at which research gets stuck in the lab and fails to reach impact). The team included a fully-functioning 3D art pipeline (concept art, 2D artists, modelers, animators, and post-production technical artists).

Norton

W. W. Norton & Company, Inc. is a mid-sized employee-owned publisher known as the publisher of the *Norton Anthology* series. Norton also publishes trade books and college textbooks, which both include accompanying digital materials. In the late aughts, Norton acquired a textbook project called *At Play in the Cosmos*, to be authored by Adam Frank, a Professor of Astrophysics at the University of

Rochester. Frank proposed that Norton develop simulations and mini-games to accompany the text. As a result, Norton began to explore games for higher education.

Subject Matter Expert Team, Led by Dr. Jeff Bary

At Play in the Cosmos employed a subject matter expert team, led by author Dr. Jeff Bary of Colgate University. The team also included Richard Townsend (UW-Madison), who was a helpful resource local to the game developers. Professor Dave Wood (San Antonio College) brought expertise teaching in community colleges. Adam Frank (University of Rochester), who is also the founder of National Public Radio's 13.7: Cosmos and Culture Blog and a regular contributor to the All Things Considered and New York Times, added expertise in communicating science to the public. Norton also recruited proposal interviewers, instructor focus groups, play-testers and classroom testers to the project.

PRE-PRODUCTION

Introductions, Negotiations and Forming a Partnership

The partnership phase of *At Play at the Cosmos* began in January 2014 through an email introduction. The time between initial introductions and commencing work was about 18 months. For six months, we explored the relationship, kicked around ideas, and settled upon a scope. While GLS conducted an environmental scan for similar games, brainstormed ideas and formed a proposal, Norton team members generated internal support for the project. Two ideas drove this phase of the design discussions:

1. What type of game framework (genre, narrative) could tie together wide-ranging content (e.g. internal composition of planets, Physics, black holes)?
2. The book includes discrete interactive demonstrations that professors use as teaching tools. Could these interactives be integrated into the game? Could these "interactives" drive down the game cost?

Games already exist that depict specific concepts such as gravity, but we did not find any that integrate concepts such as the evolution of stars. We thought the project was feasible, and unique in the market. Scoping the game within a hypothesized $500,000 development budget was the next challenge.

The **result** of this phase was an invitation for GLS to submit a **high-level document for internal review.**

Developing the General Concept (3 months)

To test the idea of a game for introductory Astronomy, GLS submitted a high-level 10 page General Game Design (GDD) document, which Norton used to generate internal support. Norton commissioned ten reviews of the GDD by instructors at two year, four year, private and public colleges and universities. Reviewers were cautiously optimistic but had a hard time envisioning a finished product. They raised concerns about balancing science with science fiction while avoiding androcentric perspectives (presenting Astronomy only in terms of human experiences of it). In spite of these concerns, Norton released a Request for Proposals to move the project forward without committing fully to making a game.

Testing the Idea and Formalizing a Partnership (3 months)

In the fall of 2014, Norton announced the Request for Proposals, which created a tricky situation for GLS. GLS had not responded to such requests because they are competitive on cost (and Universities are not); University programs like GLS are generally a better "thought partners," where they contribute significantly to the intellectual direction of the project (but are more expensive). GLS proposed a project with trepidation.

The GLS bid was warmly received in November of 2014, and Norton presented the project to their board. Over 40 editors and directors discussed the proposal across several editorial board meetings. They liked that University researchers would stand behind the project. The following questions returned to GLS:

- **Look and feel.** Were high resolution graphics necessary? Would students be impressed by essentially an indie game? Would it turn heads or be seen as passe?
- **Customizability for Instructors.** Could instructors jump to specific levels for lectures? Could levels be customized to reach specific learning objectives?
- **Ownership.** Subject matter experts, game designers, and publishing companies have copyright interests in games. In academic publishing, professors and students routinely sign over copyright to publishers. What copyright model should we use?
- **Related Versions.** How difficult is it to create versions for home, K-12 or other contexts? How are publishing rights in those contexts handled?
- **Schedule, Deliverables, and Payment.** Book publishing and game publishing have different milestones and methods for managing uncertainty. Game development requires significant up-front funding for staff.

Negotiations continued for 3 more months, and after much deliberation, Norton awarded an interim contract. The results of this phase were a proposal by GLS, Norton internal review report, and a contract to create a detailed design document.

Design Jam: Rapid Needs Analysis, Team Building, and Ideation (2 weeks)

Game Design Jam

The next phase began with a *design jam* to generate design ideas, uncover tacit assumptions, and create team cohesion. We wanted to seed a culture of respectful cross-functional communication while learning about one another's work. We broke into subteams, each of which consists of: (1) a subject matter expert, (2) a game designer, (3) an educator (learning scientist, teacher, or instructional designer), and (4) a publisher. Each team worked for half a day developing ideas to be presented to the group.

The design jam functioned as a quick and dirty *needs analysis* and *consensus builder*, similar to Bichelmeyer and Boling's (1998) collaborative rapid visual prototyping. The team operated on shared principles of valuing others' expertise and respecting the importance of each domain. Developing trust is critical for learning game projects in which design trade-offs pit concerns against another. Finite resources are dedicated to one feature (e.g. new levels) over other ones (e.g. more voice-overs for characters). Shared values can ensure that trade-offs do not trigger animosities. We were pleased when one team member (e.g. a game developer) advocated for the views of another (e.g. an Astronomer). Working in groups of 3-4 also increased each participants' opportunity to share ideas.

Game Jam Results

Through the game jam, a team identity emerged. We spent 3 days polishing designs and angst over protracted negotiations was replaced by enthusiasm for what we might accomplish. We arrived at the following values:

1. Thinking processes and arguing evidence, rather than memorization;
2. Deep conceptual understanding of fundamentals (scale, universal nature of physical law, interaction of light and matter, origin and evolution of structures in the universe);
3. Presenting evidence for *why* we know what we know;
4. Tying together concepts addressed separately in courses (e.g. how understanding the star formation rate in Galaxy factors into frequency of planetary systems).

Jeff developed a detailed 3 page list of learning objectives (see an excerpt in Figure 1):

Section II: Planets

1. Understand how planets (and stars) form from collapsing clouds of gas.

    A. Conservation of Energy (Potential energy converts to kinetic/thermal energy)

    B. Conservation of Angular Momentum (Leads to the spinning up and flattening of the collapsing cloud)

    C. Circular motion (Force required to keep an object in circular motion)

2. Understand structure and composition of a planet-forming disk.

    A. Disks are hottest nearest the star.

    B. Inside the frost line, terrestrial planets form. Outside the frost line gas giant planets can form. (Results from the availability of solid material to accrete.)

FIGURE 1. Excerpt of the learning objectives list.

GLS suggested how to translate ideas into game design patterns. These contributions included:

1. Seeding group work external to the software so that the game supports group work;
2. Using game interface conventions to introduce vocabulary situated in action;
3. Using interface conventions to connect mathematical representations to the physical phenomena they represent;
4. Recognizing and confronting limitations to software, such as managing relative scale (how to manage that the sun's diameter is 109 times the Earth so that if the Earth were one inch on screen, the sun would be 9 feet wide).

Surprisingly, little has been published about University-level Astronomy learning (see Barab, Hay, Barnett, & Keating 2000; Plummer & Krajcik, 2010 for notable exceptions). Student understanding of the seasons is well researched (see Barnett & Morran, 2002; Vosniadou, & Brewer, 1994), scientists have studied students' existing conceptions of Astronomy (see Trumper, 2001a, 2001b; 2001c; 2006), and students' conceptions of lunar phases have been researched (Trundle et al., 2002; 2006; 2007a; 2007b), but the bulk of concepts covered in this course are relatively unexplored.

Mathematical notation was a barrier for students, particularly non-majors who "thought they were in an Astrology class." For days, this question: "How to handle the math?" lingered, until we embraced this design challenge as pedagogical opportunity. Ken Forbus and colleagues' *qualitative Physics* framework describes how to build situated understandings of Physical phenomena that become quantitative models (cf. Chang & Forbus 2015; Forbus, 1997). Could a game could attach quantitative understandings to these qualitative intuitions?

Early Design Pillars

The next weeks involved committing to core design approaches.

Committing to a Narrative Framework

The "winning" design was a mission-based role playing game in which players explored space as independent charter contractors. Our inspirations included Han Solo from *Star Wars* and the *Firefly* television series. We brainstormed missions: Launching a spacecraft, exploring nearby galaxies, and identifying a habitable planet for colonization. The core gameplay loop would involve (1) addressing questions (e.g. Does this section of a galaxy have habitable planetary systems?), (2) using tools (e.g. a virtual light spectrum analyzer) to collect data, and then (3) confirming or disconfirming results (e.g. traveling to a planet to visually confirm or disconfirm). We committed to a "hard science fiction" of plausible futuristic technologies.

FIGURE 2. Star chart. Players use this chart to navigate by 1) Selecting a label (such as the Orion Nebula), and then tapping a region (e.g. Trapeseum) to travel. Faster Than Light Travel is represented through a visual blurring effect (as is done in popular films).

Key issues: navigation & scale

Navigation was a challenge:

1. How do players navigate? Video game flight controls are notoriously difficult. How scientifically plausible do the ship's control systems (e.g. thrusters) need to be?
2. How do we represent size and scale, given how small a ship is compared to celestial bodies?
3. How would players travel to different galaxies? Saturn is 4 light years from Earth and the nearest galaxy is 25,000 light years away. Is it reasonable to include "Faster than the Speed of Light" travel? Without some sort of hyperwarp, *Cosmos* would involve literally years of sitting in place.

Faster than Light (FTL) navigation and interactive star chart

Professors Frank and Bary articulated a plausible method for ships to travel faster than light speed. We could have stalled on this design problem for weeks, which would have derailed the project. Having a solution developed by world-leading astronomers themselves was crucial.

The **Interactive Star Chart** sought to achieve three goals: (1) aid navigation, (2) scaffold students' learning scale and structure of the universe, and (3) overcome technical memory limitations associated with rendering the entire universe on a mobile phone. Imagine, in contrast, representing the universe as one continuous system with no navigational signposts; students would largely "fly blind," getting no sense for how the universe is organized. In contrast, repeatedly interacting with Astronomical labels (see figure 2) might reinforce structures.

Embedded tools

We included authentic astronomers' tools in-game as "verbs" for players to use. Each tool is introduced during a mission and includes an embedded tutorial. We identified seven tools to develop, such as:

- **Small Angle Tool.** Used to measure the angular sizes of objects and employs the small angle approximation to calculate physical size.
- **Spectrum Analyzer Tool.** Used to collect and analyze spectra of celestial objects including stars, supernovae, and nebulae.
- **Radial Velocity Tool.** Used to measure the Doppler shift of spectral absorption or emission features from two-dimensional spectra of a celestial object. Using the Doppler shift equation for light, students calculate the radial velocity of the object as a function of time to produce radial velocity curves.

Tools became a guiding framework for mission design involving thinking with data.

Making the Abstract Concrete: Articulating A Vertical Slice (6 weeks)

We next designed a vertical slice mining asteroid in Exoplanetary System HR 8799. A vertical slice is highly polished "slice" of the game that includes high-level top-level functionality (such as the ability to navigate), while also drilling down on other systems. A vertical slice requires the team to consider how subsystems (such as user interface, mission systems, and player data) interact (Lawrence, 2016). Stakeholders like that vertical slices create an early, coherent version of the play experience and force teams to reconcile early how software subsystems (and teams) interact. Designing a vertical slice of *Cosmos* required designers to articulate technical requirements and what media assets are needed. This slice included: 1) A Mission, 2) Interactive Simulation, 3) Smartwork Demo assignment (homework questions based on the book's explanation of mission content), and 4) an ebook demo. The vertical slice required us to think through the entire user experience and technical flow.

We decided to build Cosmos with the Unity framework, porting to iOS (iPad 4 & iMac), PC and Android tablets. Data would be stored online on Norton servers, which was important for FERPA regulations and for stakeholder data ownership issues. The interactives would be stand-alone, HTML5 and available for offline use, but also accessible via game play. Most learning projects with clients have a similar pattern: The game needs to be accessible offline but also have secure data storage in an institutional database.

Game design document

Lead designer and project manager Mike Beall spent about one hundreds of hours reading and talking with Astronomers. The design document became 28 pages long, including concept art, mock interfaces, and links to sub-documents (e.g. missions, systems engineering planning). Subject matter experts regularly read and returned documents with line-by-line edits within 24 hours, and most importantly, they shared responsibility for the game's quality. We were an integrated team rather than functioning in a traditional developer-expert relationship.

The art team, led by Brian Pelletier gathered research art and developed concept art for the player's ship, command center, and world (see figure 3a and 3b and 4). We sought a clean, futuristic look. Graphic Artist Jacob Reusch researched interfaces, drawing heavily from the work of Jayse Hansen, the

FIGURE 3A. Conceptual Art of Player Ship.

FIGURE 3B. Conceptual art of a space station in the world.

FIGURE 4. Early Tool Interface mock-ups.

FIGURE 5A. Gas Retrieval Mission Mock-up.

FIGURE 5B. Early Mock-up of Tools within the Heads-up Display.

UI designer behind the Heads-up Display of Ironman's suit in the Marvel film franchise (see figure 4). *Ironman* made an excellent reference piece because it included all of the controls and data streams required to navigate an Ironman suit. Nothing that appears on screen in the *Ironman* HUD is gratuitous.

Missions: A tool for aligning game play & learning objectives

We designed the game through writing *missions*, such as figure 4, in which the player gathers Helium 3 from the Horsehead Nebula. This mission's learning goals were to understand blackbody radiation and Wien's Law, which involves calculating the temperature of celestial bodies based on light waves (see figure 5). We wrote a narrative arc in which a rival corporation detects the player, so the player must act fast to escape detection. This narrative gave hint to a broader world beyond the character.

Interactive simulation design.

Professor Jeff Bary wrote a 143-page design document for all 49 interactive simulations, which was a pivotal step in the game's development. The list provided: 1) a comprehensive scoping of the domain, 2) descriptions of *systems* that could become game scenarios, and 3) representations to help non-Astronomers understand the domain. A design doc of interactive simulations was the perfect way to teach the team Astronomy. We now had an authoritative structure to design around and think with. As game designers, we immediately began making interactive interfaces "juicier," which means to amplify inputs or outputs to make simulations more engaging (Juul, 2009; Poole, 2001). For example, the spectrometer was redesigned to include visual animations and sounds that made the process feel "alive." 29 of these simulations ended up in the game.

PRODUCTION: GETTING TO ALPHA

Compared to our academic projects, *At Play in the Cosmos* followed a relatively linear, waterfall-style design, driven by the exceptionally long pre-production period (cf. Gaydos & Squire, 2012; Paiz Ramirez, et al., 2011). The compressed timeline left little room for dead-ends, so the team needed to pick a direction, commit to it, and go. There was no major change to the game focus, nor changes to the core game loop.

Navigation, Controls, and Game Play

Flight controls are notoriously complicated because they involve navigating in true 3D without any floor as a reference point (see Holland, Jenkins, Squire, 2003). Touch interfaces offer new solutions, and hundreds of games from flight games to bird simulators are experimenting with control schemes.

Tap for directional orientation

Cosmos underwent frequent user-testing with 100s of students recruited through the GLS "PlaySquad" program.

(PlaySquads were community partners identified at visits to schools, community centers, or lab tours). We developed 12 iterations of navigational interfaces that were tested with 300 players before arriving on a "tap to determine direction" interface.

The Heads Up Display (HUD) provides cross-hairs in the center of the screen that indicates direction (see figure 6). Tapping on the screen adjusts the ship's orientation to that direction. On the lower right side of the screen (near the thumb), the player moves thrusters in forward or reverse. We experimented with using the accelerometer for navigation so that players would move the iPad like a steering wheel. That approach was promising, but felt like a novelty and distracted from Astronomy.

Thrusters

We tested 3 major control sets for thrusters. We considered options like a true forward and reverse (which would require reversing thrusters to slow down), putting thrusters in the HUD (which was too complicated), and on-screen speed indicators. Giving the players visual cues of speed was difficult, given astronomical scale (players cannot intuit velocity from physical surroundings). The final design includes a numeric indicator of velocity and a sliding speed thruster (controlled by the thumb). This design:

FIGURE 6. Final game interface.

			Month 1	Month 2	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15
estimated starting month	may	june	july	august	september	october	november	december	january	february	march	april	may	june	july
				Road to Alpha					Road to Beta			Road to Gold			
Milestones - Goal for what is completed by the end of each month	High Level Concept	Full Production Starts - Systems, Art pipeline	Start Physics Level	Start levels 2-4	First Playable	Start data collection	Alpha of Levels 1 - 4	Iteration and bug fixes	Testing of Full Game 1- 4 to Beta	Beta for class testing	Research Testing with UW Starts	Iteration and bug fixes	Efficacy Testing Ends	Polish	Gold - Finished Game
Details	research	proof of concept of narrative and interactives	Start integration with LMS	missions, interactives	IRB Submitted		testing LMS integration	Final Data Collection	Iteration and bug fixes	Iteration and bug fixes	Continued polish to game and interactives		Iteration and bug fixes		
Details		detailed walkthrough of physics level	detailed walkthrough of levels 3 - 4	Final pass on scientific accuracy with SMEs			iteration and bug fixes			Sites finalized	Iteration and bug fixes				
Details		cirriculum designed for levels 1 - 4	Start Interactives	Test Interactive import / export to / from Unity		Revisions on First Playable	Research Site finalized					Executive Summary of Research findings			Article submitted to Research Journal (JSET)
Details		Final SOW GDD Marketing Materials													
Events	Design Charette focus group			american astronomical Society focus group						class testing					
Deliverables (1st of each month)															
Major			cirriculum designed for levels 1 - 4	Detailed Walkthrough of Levels 3 - 4	Final pass on scientific accuracy with SMEs	First Playable ver 1.0	ver 1.1	Alpha of Levels 1 - 4 ver 2.0	Data Collection reporting to Dashboard and LMS	ver 2.2	Beta of Levels 1 - 4	ver 3.1	ver 3.2	Efficacy Test Paper	Gold

TABLE 1. Project Timeline and Milestones. Most project management occurred through such spreadsheets that coordinated details across teams and systems. These include a range of tasks including game production tasks (number of levels completed), curriculum goals, focus play tests, and systems such as sound. Key milestones (such as IRB due dates) are written in blue.

- Did not require constant manipulation, which addressed novices' needs for simplicity (players cold stop at any point by selecting neutral);
- Enables action-oriented players to "ride the thrusters" and guide the ship moment-to-moment as desired.

Flight-based game play

Tapping for direction combined with thrusters created flight, and the team turned to making flight-based game play. *Within* regions, players have full control over their ship and freedom to interact with astronomical objects. We created action-based game play within missions by analyzing flying and racing game tropes. Players collect objects, fly through obstacle courses, and avoid traps. Considerable iteration occurred as the team realized it was essentially making a flying game.

FIGURE 8. Concept Art of Game interface and tooltips. Tool tips were provided for astronomical structures to provide just-in-time learning opportunities.

Working Vertical Slice Demo and Regular Builds

We chose the January 2016 American Astronomical Society Conference as a deadline for the vertical slice. A public showing only 4 months away would galvanize the team. If these functions worked within 3 months, the risks of the project failing would go down.

Similar to agile software development, we started a process of regular playable builds to answer production questions. The first playable build was October 21, 2015, which was about 6 weeks after the project kick-off. Major updates occurred bi-weekly. As an example, the following feature list was added November 7th, 2015 (about 8 weeks out):

- scaleable UI system
  added functionality to in-game lighting
- Interactive for Newtons version of Kepler's 3rd Law
  menu system to select missions (this will eventually be populated will all missions)
- flight test scene
- scale test scene
- login screen
- ship naming UI
- ship color selection with locked color options
- ship intro UI detail views of parts

Only 8 weeks in and developers were worrying about issues such as "ship color selection," because we needed to see the final art in the game. Importing final, high resolution art into the game can create problems because the files are larger. In addition, final art changes the look and field, and the visual field can become too cluttered or heavy with the high resolution images.

Art Test With Focus Groups

The artists insisted on frequent focus groups. Questions included, "What feelings does this conjure?" or "What would you expect this game to be about?" These conversations led to three guiding principles: (1) Near-future, hard science fiction; (2) A ship that is a scientific vessel, but could also defend itself; (3) A ship that was fast. Ship *speed* reappeared across groups as a key feature.

The ship took on a submarine-like quality and Jacques Cousteau became an inspiration (see figure 9). Multiple ships were developed to give players choice.

Most academic teams have an artist or two, but creating industry-grade games required us to invest heavily in art. Our team included up to 6 artists, including Studio Director Brian Pelletier, who has over 20 years AAA game development experience and has directed multi-million dollar projects such as *X-Men Legends*. Figure 9 depicts ship rendering that includes weathering, an effect that helps give the ship a sense of history. Effects such as weathering give the world depth and suggests how artists think about design, compared to many programmers or educators. Whereas one artist working alone has to "do everything," a team critiques one another's work and develops specializations.

Negotiating Depictions, Accuracy, Game Play

The editorial team focused on *end-user requirements*. As developers, scientists, and educators "geek out" in a domain,

FIGURE 9A. Early ship concept art. Early ship concept art was intended to give a general sense of geometry and functions, rather than a definitive number of functions.

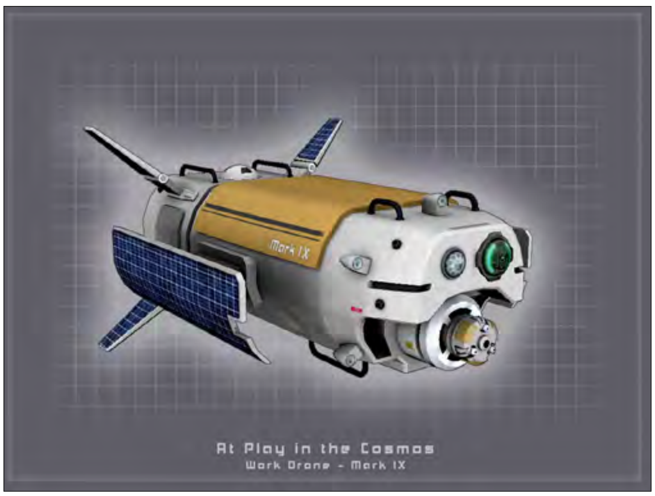

FIGURE 9B. Ship with weathering.

they often go down rabbit holes of detail. Here, developer **Mike Beall** asked astronomers:

> *Can you give us detailed information (fictional but plausible) for 3 sets of binary asteroids (assuming they are mostly spherical)? We need (Mass, Diameter, and distance from ship to asteroids in kilograms/kilometers for each). Example:*
>
> *Mass = 100,000 kg*
>
> *Diameter = 67 km*
>
> *Distance = 350,000km*
>
> *We are using Mass, Volume, and Density to determine the best candidate for asteroid mining. How do we explain this to the player?*

As a part of his response, **Jeff Bary** offered the following vignette:

> *The goal of this mission is to have students learn and recognize which observable characteristics of the binary asteroids allow them to determine the masses and sizes of the asteroids. Then, they need to recognize that the mass and size allows them to calculate the density. Density allows them to determine the composition of the asteroids and thus determine which one or ones are most suitable for mining.*
>
> 1. *Choose a density for the asteroid or asteroids*
> 2. *Choose a radius/diameter.*
> 3. *Use #1 and #2 to calculate masses for the asteroids and note the ratio of the masses.*
> 4. *Choose a separation or total semi-major axis. (Separation will be a property that students will measure.)*
> 5. *Use the small angular formula, which relates the physical size and distance to the object to calculate the angular size of the asteroids. (Angular size will be a quantity students will measure in the game).*

Rob (an Editor from Norton) responds to pull the team out:

> *The calculations required in this workflow make me nervous. In the book, all math is optional (covered in Going Further boxes) because we know how few instructors require calculations as part of the course. In fact, only 10 of the 45 problems at the end of each chapter require calculations.*

My worry is that this workflow reads a bit more like a script for a quantitative online lab as opposed to a game where students learn intuitively through play (emphasis added).

Erik Fahlgren, an Editor and Vice President at Norton echoed Rob's comments.

> *I want to echo what Rob is saying. The vast majority of this market does not teach or expect students to use ANY math. Ratios (if this is twice as large, how much faster will it go) is the extent of math used at most schools.*
>
> *Asking students to DO math in the game would be an astronomical mistake.*

This exchange exemplifies how the game was designed and how respective roles contributed.

Scaffolding Mathematical Representations

We revisited the idea of how to connect celestial bodies to mathematical representations of their relationships. We enabled students to manipulate variables and see how numbers changed in equations. Everyone recognized this potential of the game, as suggested by an email sent by Adam Frank in November:

> *So I am digging the new build and the ability to see just the equation with variables or with #'s but it leads to a super important killer question which, if we get it right, might really let us break through. The question is this: How to let students get a "feel" for the behavior embodied in an equation?*

For example, consider an inverse law: Y = 1/X

I would be so happy if my students really understood that as X gets bigger, Y gets smaller and vice versa... This issue will come up for every interactive with an equation and if we get it right we will be heroes.

We developed a new game play model in which players directly manipulate equations. For example, in the third mission, players search for iron deposits inside of asteroids to repair their ship. Using the mass analyzer tool, players identify an asteroid with iron deposits. They measure the orbital period of debris orbiting an asteroid, which they next use to calculate the mass of the asteroid. Once the mass of the asteroid is determined, they use the small angle formula tool to calculate the diameter of the object, which together, can be used to calculate density.

This mission illustrates the core game loop: Players learn astronomy through asking questions (does that asteroid have iron?) and using tools to answer them. The designed intent

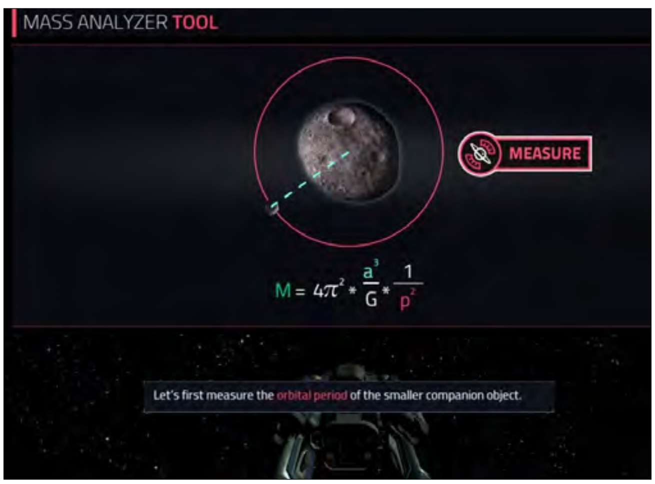

FIGURE 10. The player is introduced to the mass analyzer tool. The player begins by measuring the orbital period of an object.

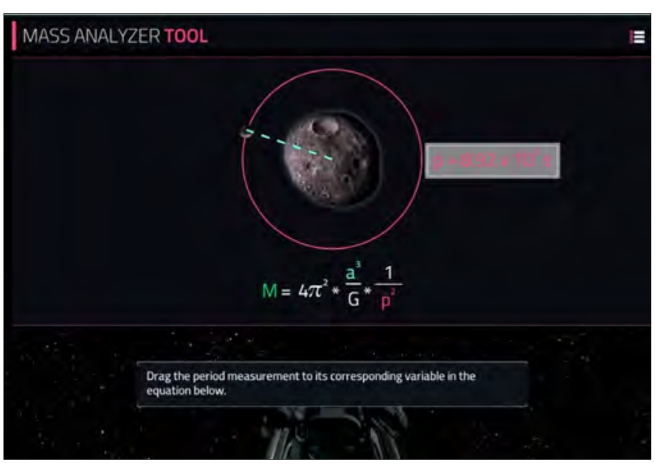

FIGURE 11. The player can drag the numerical value of the period into the equation by matching the red numerical value (p) to the red variable (p) in the equation.

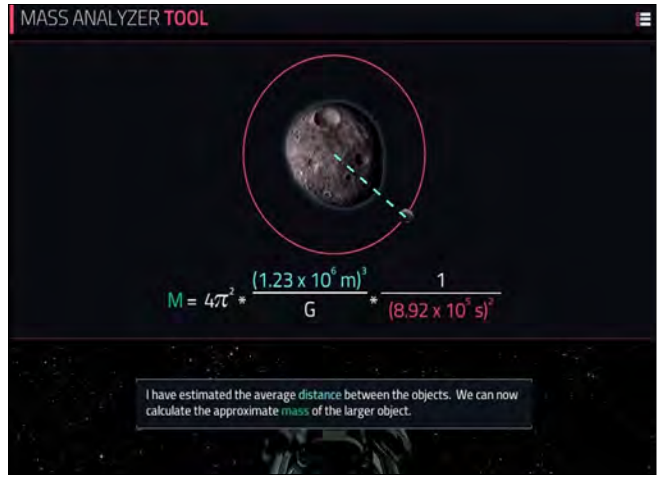

FIGURE 12. The computer estimates the distance between object, once the orbital period is known, which can be used to calculate the mass of the object.

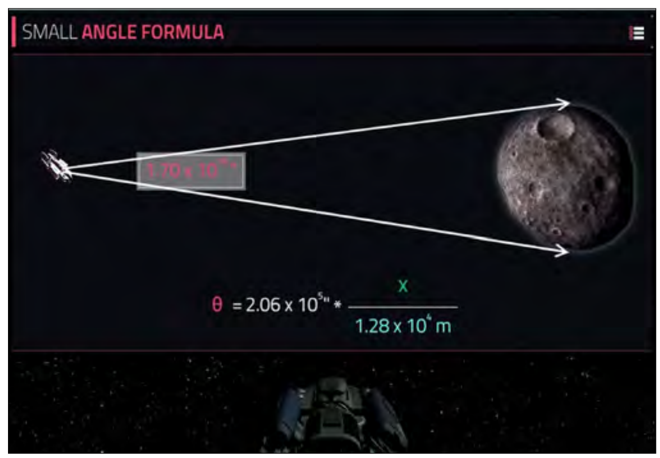

FIGURE 13. The player calculates the angle created by the boundaries of the celestial object, which can be used to derive diameter.

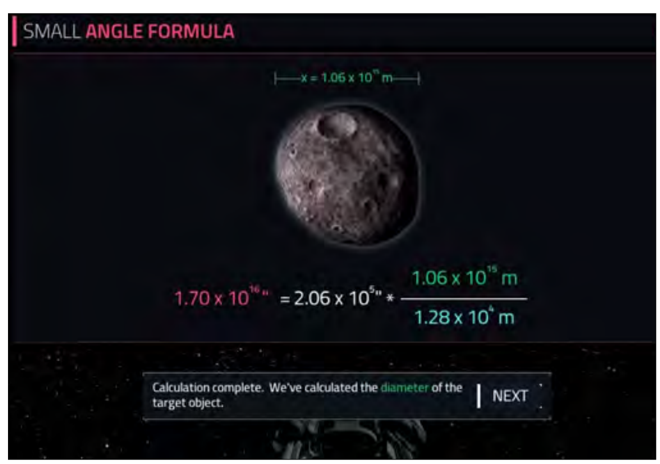

FIGURE 14. Small Angle Formula Mission complete.

was to include multiple missions so that players develop fluency over hours of play.

C.O.R.I In Game Narration to Address Non-Gamer, Non-Science Majors

A formal play test in October 2015 with 35 students (which was in addition to regular testing (informal, frequent "Kleenex testing" testing) raised new questions about scaffolding non-gamers. Most students chose to be independent contractors completing space rescue operations. They liked exploring the unknown and saving the human race, but not so much the military themes. Preferences coalesced around sleek, fast ships (as compared to more bulky cruisers) with a distinct personality. We committed to the following formal specifications:

1. Form the storyline around exploration and adventure. The main character will complete rescue and recovery missions in space.
2. Use the color blue for neutral, exploratory space missions. Blue transforms into red whenever danger is imminent. Yellow will represent caution upon approach.
3. Include an Artificial Intelligence on the ship with a distinct character.

An in-game narrator (such as Jarvis in *Ironman*) would guide players, especially non-gamers. We recruited Professor David Simkins (RIT) to narrate and become the Cosmic Operational Research Interface, or (C.O.R.I.). C.O.R.I. would be calm, confident and reassuring to the player. We hoped that C.O.R.I. would personalize the experience and mitigate science anxiety..

January Playtest

In January 2016, Norton presented the vertical slice to Norton Directors and Astronomers. Consensus was that:

1. *The visuals looked great*. The game sparked imaginations, the production quality impressive, and participants wanted to see the game published.
2. *The game was too didactic*. The missions, based on the "workflow" provided by professors felt formulaic.

This feedback echoed our own concerns, although we were at peace with our progress: If the core game play was sufficiently academic, we hoped to increase engagement through narrative, choice, and polish (Schell, 2008).

THE ROAD TO BETA

With core game ideas, missions, and systems functioning, we fleshed out the narrative by building missions, creating art assets, developing interactives, and creating the flow for data to be collected, stored and fed into the Norton Learning Management System. Design at this stage involved exploring content in fine-grained detail, thinking through mission specifics and assembling assets. Each mission underwent thorough vetting.

Art Pipeline

Artists created 190 celestial objects, each of which included 19 variables. Reference art was easily obtained through public repositories. Artists still made interpretive leaps, such as how to represent and label portions of the galaxy. As the art came together (see figure 15), project momentum grew. Seeing space ships and celestial bodies *working in game* inspired team members (who frequently shared excited comments over email). The team managed largely through generating enthusiasm, rather than explicit directives. Team members motivated each other through inspiration and surprise (see Bacharach, 2006).

Sprint Schedule and Meeting Process

Communication was managed through documents, and there were now over 50 such documents tracking everything from narrative story arc to internal scientific language standards (see Table 4).

Crafting System

As the number of crafting missions grew, we created a stand-alone crafting system. A stand-alone crafting system enables players to locate materials in the universe and transform

FIGURE 15. In game art coming together. In this image, the spaceship has textures, and the thrusters include particle effects. The image also includes a camera lens effect, in game lighting systems, and celestial objects. Determining appropriate scale and level of detail for celestial objects was non-trivial.

					September		
2		Sprint 1 - 8/26	Sprint 2 - 9/2	Sprint 3 - 9/9	Sprint 4 - 9/16	Sprint 5 - 9/23	Sprint 6 - 9/30
3	General Code			Enemy Ship AI	Star Chart resource images		Mines polish - tracking and explosions
4	Missions		Start Mission 10	Start Mission 9	Start Mission 11		Start Mission 12
5	Missions		~~Volumetric Unity Functionality - GREG~~	~~Volumetric Unity Functionality - GREG~~		Mission 6 polish	Mission 6 - 11 Polish
6	Tools	reduce delays in small angle tool progression	add more comparison spectra for star types				
7	Tools	Stop all VO upon exit from tool	Implement drag & drop mechanic for tools				
8	Tools						
9	Artwork	Saturn's rings FTL environment	add Proxima b	Shields			
10	Artwork	Ant Nebula	tbd	Lasers			
11	Artwork	Comet Artwork	Comet Artwork	conceprt for in game HR diagram			
12	Artwork		Upgraded FTL particles	concept for habitable zone pop up			

TABLE 4. Sample Sprint Schedule. Tasks are broken down across teams and intended to give a relative sense for task intensity (e.g. Artificial intelligence for enemy ships is a one week task).

them into resources such as fuel. This system required not just new player capacities and interface elements, but variables that defined which resources each celestial body contained. The crafting system reinforced that the Universe is made of elements that can be broken down, used and processed, and that future space exploration may rely on such activities. Aesthetically, the crafting system sought to deepen the player's bond with the spacecraft, enhance a sense of independence, create open-ended game play, and drive forward missions narratively. A spreadsheet tracked each element, how it is useful, and where it is found. The crafting interface was inspired by the game *Faster Than Light*.

THE ROAD TO GOLD

Final Development Production Goals

By fall of 2016, Cosmos was a recognizable game, with the major systems intact, but publishing a game for dissemination required additional polish. Remaining development tasks involved refining game flows, such as refining the tool progression to make the game feel less linear. Committing to a racing style game also required polishing levels, which included adding gas and particle collection systems, systems for helping players while stuck and updating players on progress. In short, we needed to make it a real flying game.

Fall Playtest

We conducted a final playtest with the alpha build. Astronomy Professors at the University of Wisconsin-Madison and Colgate University enacted *Cosmos* in their courses with 184 students directly, and 660 students interacted with the game in some way.

Overall Perceptions of Game Experience. Students reported enjoying the game and felt as if it helped them think about Astronomy. Professors regularly used interactives for demonstrations, which students recalled and valued. Most students preferred to see the game offered as extra credit, a supplemental guide, or a basis for lab discussions. Still, students felt that missions were too didactic. Few students even realized that the game's exploration mode existed. Without time to overhaul the game, we rebalanced missions and created more missions with open-ended exploration.

Formulas. Formulas remained a focal point. At the University of Wisconsin, students were introduced to formulas via a single PowerPoint slide during class lecture. The beta version of Cosmos displayed formulas (see figure 17), and then players would instruct C.O.R.I. (the ship's artificial intelligence) to calculate the equation. Students wanted more interaction with formulas, such as the ability to decompose formulas or directly manipulate them. Some students suggested directing imputing and calculating values, but the design team rejected this approach for fear that it would alienate less mathematically inclined students.

FIGURE 17. Less interactive version of creating formulas with C.O.R.I. This interface displays formulas, but players cannot manipulate them directly.

Final Additions

In the final months, 5 feature sets were added, including a final redesign of the interactive Tools and Formulas. The tools were revamped with a "drag and drop" functionality so that players select numerical values and drag them into formulas. They can move and interact with formulas without having to engage in actual calculations. Fifty additional lines of supporting text and voice over were added. The eight playable missions were expanded to twenty missions that included new visualizations. A time travel feature was added so that players can visit the Universe as it existed 13.8 billion years in the past. This feature was added because it was mentioned in playtests, it was relatively easy to implement (all of the assets existed), and added a sense of adventure.

Storyline. The final narrative closely follows the mythological archetype of Joseph Campbell's *Hero's Journey*. In the narrative, players learn more about how the Corporation is using alien artifacts to maintain a stranglehold on the resources supporting mankind's expansion out into the cosmos. In mission 19, players save the galaxy from Corporate control by unleashing a nano-tech virus that disables the Corporate space station. The *hero* is transformed by realizing her ability to use Astronomy to solve problems.

Steps Not Taken

Amidst the excitement of publishing *Cosmos*, we still had dream lists of features to add or adaptations we would have made, given more time and resources.

1. *More open-ended play outside of missions*. We imagined the game being more open-ended and supporting of discovery, so that (for example), players might explore the Universe via the star map and visit celestial systems as they wish. We envisioned the game play at its most advanced, involving emergent quests in which players use knowledge to, for example, locate and collect Helium. We wanted the universe to be a game board so that the player uses knowledge of underlying systems to maximize goals.
2. *Opportunities to interact up-close with stars and planets.* The missions take place near planets, but outside of their atmosphere. We wanted landing missions (such as lunar lander) and missions located on planets involving rovers or exploration.
3. *More complex mission structure*. Cosmos includes a relatively linear set of 20 missions that came together late. Minimally, we wanted side missions and quests, perhaps tied to factions, to increase player choice and create agency. Ideally, these would tie to competing factions (perhaps one mining for profit, one seeking a universal world order).

REFLECTIONS

There are no commonly accepted models for educational game development. We doubt that any one model will ever emerge. Developers will navigate project goals, resources, and constraints as appropriate. In the case of *Cosmos*, the extended pre-production time, which took more time than production itself, led the team toward a relatively linear design process. This pattern was dictated by publishing realities: Educational publishers minimize risk by defining the product carefully, bringing the product into focus through progressively realized designs, and conducting extensive user testing.

These steps were good, but they meant locking down the product early. In a more agile approach, we would have built a ship flying through space early on, along with some simulated galaxies and studied more extensively what users wanted to do. Such a prototyping-driven approach, in which the team would let the project emerge through cycles of building and testing, would not work in this context.

Design Walk-Throughs and Final Game Play

The design process was driven by design vignettes, or "workflows" that were guided-walkthroughs. These workflows drove the game that was ultimately built. In essence, designers wrote descriptions of the play experience from the player's perspective to describe how the player would think during game play. This process of designing through vignettes is somewhat common in the early phases of game design, as designers attempt to create an idealized experience and then design backwards to make the systems that would enable such game play to arise. The vignettes helped us understand what systems and assets to build, as in the vignette presented in 4.6, where Jeff Bary describes the process by which a player determines the suitability of an asteroid for mining.

This vignette-driven process of design has been used to theorize the nature of games, interactive narrative, or how one designs for emergent interactions (see Squire, Jenkins, Tan & Holland, 2004). A hypothesized benefit of this approach is that it allows designers to create the conditions under which the *thinking* of a domain arises (such as diagnosing a patient or analyzing a star) rather than a student memorizing information. This vignette-driven approach worked in Astronomy, where we wanted game play to revolve around using Astronomers' tools and thinking with data.

To some extent, we succeeded in this goal of designing game play that engenders thinking with Astronomy. The designed missions look like the steps proposed by Bary and the design team. The missions increase in complexity so that by mission 18, players combine skills learned in earlier missions to solve more complex problems. Still, the relatively short game duration, linear mission structure, and lack of sandbox play meant that players did not apply these tools flexibly in a variety of problem spaces and conditions.

Other training simulation games have wrestled with balancing mission-driven tutorials and open-ended experimentation. In *Full Spectrum Warrior* (which is quite similar to *Cosmos*), for example, players role play as soldiers conducting Military Operations in Urban Terrains. The game, which was built by USC in conjunction with the US Army as an entertainment game and training simulation, contains 8 missions that walk the player through learning basic formations and procedures. There are few opportunities to experiment with these skills in open-ended ways, so the game essentially feels like giant tutorial for a game that does not exist.

It is perhaps not surprising that the final product looks a lot like early written workflows. In most respects, this approach worked; the game is, if nothing else, a representation of how Astronomy tools can be applied to an interactive universe. The game play work flows and missions, although constraining, minimized a risk of failure. What we gave up in exploratory game play, we got back in a focused experience.

Process and Product

Reflecting on our process, we see that early design *processes* (such as vignettes) shaped the final form that game play took. Writing game play as steps might could lead games naturally toward such procedural game play (as opposed to games written initially as rules). As we experienced it, the form of early design representations (e.g. storyboards or lists of rules) shaped subsequent designs.

Our development process shared features with agile development. Regular sprints created a progressive focusing that brought the game closer to fruition. Each iteration was shared with dozens, if not hundreds of students in the target audience so that we had an increasingly good grasp how the game was working and where it was not. By the "implementation" phase, Cosmos had been tested in so many classes that we knew, with some degree of certainty, how it would be used.

The case of *Cosmos* also reminds us in the case of educational games (and perhaps all instructional design) that innovation comes over the course of several games and projects. *Cosmos* built on the team's prior successes and to some extent, borrowed from existing designs. We would hope to borrow from this experience, so that our educational games five or ten years from now *will* include some of the open-ended sandbox play that we would have liked to have created. As such, we will always be wary of those seeking summative judgments on whether any one game (let alone the medium) is effective.

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