Mc Graw Hill Education

Leveraging Game-Based Learning for STEM Education: The Benefits of Non-Linear Instruction

By Matt Haselton, Dan Norton and Dan White

Table of Contents

Learn more about our Science solutions. Visit mheonline.com

1

Introduction

Most academic content is taught linearly, taking students from topic A to topic B with as little deviation as possible. This approach makes good sense for subjects, such as history, that are based on a chronology of events. Linear teaching is also one of the most efficient methods for presenting a large swath of information to a full classroom. However, some academic topics are difficult to explain as points on a timeline. STEM (science, technology, engineering and mathematics) subjects, for example, are best taught through hands-on, problem-solving activities that help students understand causation and the wide range of possible outcomes.

The increased use of digital tools in K-12 classrooms has made it easier for educators and students to access game-based learning programs. This paper examines the benefits of game-based learning and, more specifically, how it can support the teaching of STEM subjects.

Leveraging Game-Based Learning For STEM Education

Game-based learning allows players to navigate an open-ended problem space that encourages them to logic their way to a variety of solutions. This kind of decision-based experience has a wide range of educational benefits for any content area, but especially for STEM topics, which are built around teaching thoughtful inquiry, deep understanding, and meaningful discussion.

To successfully leverage game-based learning for STEM education, educators must look for quality programs that encourage strategic thinking. Sid Meier, Director of Creative Development for Firaxis Games, which focuses on simulation and strategy games, believes that a well-designed game should provide players with interesting choices that:

1) present the player with a trade-off between advantages and disadvantages;

2) are situational, requiring the player to contextualize their decision;

3) are personal, allowing the player to make a choice that is significant to them and their strategy; and

4) are persistent, meaning that the outcome of the choice has some consequential ripples.

STEM educators who want to leverage games for more open-ended learning may find that games with these qualities are more engaging for students, too.

Encouraging Scientific Thinking

If good game design is built around player choice, and specifically around how the game responds to the player's inputs, then player's must know how to speak the game's language. Game systems, commonly referred to as "rules," help players navigate through gameplay by creating logical if/then scenarios. For example, "If I roll a six, then I can play a card," "If the monster is wounded, then I can move ten spaces."

To master a game is to master its systems. This mastery is, in and of itself, a game of players forming, testing, and revising their hypothesis through strategies. So, it's no surprise then that games are a natural fit for teaching STEM topics, which frequently emphasize the scientific methods of observation, measurement, and experiment, as well as the formulation, testing, and modification of hypotheses. As an interactive medium, games allow players to practice these essential techniques in a way that more traditional/linear methods cannot.

Here is a good example of a game-based STEM lesson:

Pinball: Energy Challenge is a digital game that teaches the physics of energy transfer through a variety of whimsical pinball challenges. The player's objective is to maneuver the ball to the goal, and they are given a toolbox of elements they can freely apply to the playing field to help them along the way. These include banked surfaces to adjust the ball's trajectory, low-friction surfaces to help the ball maintain its speed, and wacky generators that siphon off the ball's energy.

The core of the gameplay requires the player to hypothesize about which objects to use and where to place them on the field to guide the ball around the obstacles and into the goal. Inevitably, the player will formulate multiple hypotheses (and make multiple attempts) as they work to solve each level's challenges. This cyclical process of trial-and-error is a natural part of gameplay as well as the scientific process, and the game provides students with a hands-on way to practice engage in both.

Providing Interactive Models

If we think of classroom content existing somewhere on a matrix of interactivity and fidelity, there's typically a direct correlation between the two. To frame this in terms of STEM, the more "hands on" an experiment is, the less abstract it is. In other words, there's a huge difference between viewing an explicated diagram of a chemical process and mixing two chemicals together in a beaker to view the reaction.

Both ends of the interactivity/fidelity spectrum have value as teaching tools, but the nature of limited instructional time requires instructors to choose one over the other. One of the greatest benefits of game-based learning is that educators can simultaneously leverage the benefits of both.

As outlined in the previous section, interactivity—or player choice—is a valuable teaching tool for encouraging scientific thought. Fidelity and abstraction are tools that support and frame that scientific thought-process. In any teaching endeavor, the raw quantity of information presented is rarely the best metric for evaluating the quality of the lesson. Teachers and textbook authors spend huge amounts of time trying to create mental models that demonstrate both real-world accuracy (aka fidelity) and straightforward understandability (aka abstraction). Finding a way to bridge this gap is invaluable, particularly for STEM content that is intrinsically rooted in the scientific laws of the natural world.

Scientific and mathematical content is often invisible to the naked eye. For example, we must imagine the erosion of a landform or the growth of an organism that we have never seen. Some information may be on a size scale that is outside of human perception, from universal to sub-atomic. Turning that information into a static image on a page, or even a lab experiment in a petri dish, can't truly showcase the reality.

When presenting content through traditional mediums, it seems the more abstract content gets, the more brittle it becomes. Many metaphors work on a basic level, but when they are extended, they quickly fall apart. Games, on the other hand, are dynamic. They are built from player inputs, so events occur more naturally in response to external stimuli. When players make decisions, they are virtually "kicking the tires" of an idea.

The topics games present require this user input to function, and they present content in a way that encourages that input. Good game design doesn't hide choices from the player, but puts them front and center, urging the interaction necessary to proceed. At times, that interaction is not based in reality, but rather presents metaphors that help students progress.

A great example of a metaphoric gaming model is Inspire Science's *Animobile*. In this game, players drive a titular vehicle around the world to learn about different animal attributes. In a Magic Schoolbus-esque twist, the vehicle itself takes on the attributes of certain animals to solve environmental challenges. For example, it may acquire a frog's webbed feet as a way to cross a marshy swamp or an ant's enormous strength to lift an obstacle out of the way. This game offers a simple, yet fantastic way to represent the way specialized animal anatomy works. Rather than teaching content on a 1:1 scale, *Animobile* essentially creates interactive metaphors to highlight key concepts. And while the idea of a van sprouting wings or growing claws is clearly absurd, it is an effective way to help users connect animal abilities to specific physical attributes.

Taking A Non-Authoritative Approach

Whereas the humanities tend to require a more qualitative approach to content, STEM topics are generally quantitatively taught. By nature, emphasis on measurable data (at least in introductory classrooms) can discourage students from expressing their personal opinions or interpretations of the content. This is unfortunate, since discussion can be a valuable teaching tool when properly facilitated. The nature of games makes them an excellent tool for engaging students in such discussions.

A game does not exist without the input of a player. In other words, the player/student is effectively a co-author of the experience. Unlike traditional media, games give players fewer reasons to critique the experience, because they have intrinsic ownership over their game and its outcome. With traditional teaching approaches, standards maybe challenged as unfair or

Learn more about our Science solutions. Visit mheonline.com

4

unbalanced, and the general mentality is often that the "house rules," because STEM content that is often seen as beyond reproach. This isn't to suggest that students' critiques are correct or that STEM content itself should be altered to fit their whims. Instead, it highlights the need for a shared experience around STEM that can be discussed in personal terms, rather than strictly quantitative academic ones. Just as games can transform eons and atoms into tangible play elements, they're also a natural tool for facilitating the kind of conversations that aren't always part of today's scientific instruction.

A Non-Authoritative Example

Space Habitats is a game that highlights the potential for a slightly transgressive approach. The game teaches players about the relationship between animal anatomy and their environmental habitat. Players run an intergalactic pet boarding business, and they are responsible for taking care of a host of fictional alien species by reviewing their anatomy (e.g. fur thickness, size, diet). Players must also custom-create an environment to meet the needs of their alien pets. After a set amount of time, if the player has constructed an appropriate environment, the pet's owner can pick them up and leave in a shower of star confetti. Conversely, if the player does not create an appropriate environment, the pet stamps its foot and leaves in a huff.

In the real world, taking care of an animal is a tremendous and complicated responsibility with serious consequences for miscalculations. In contrast, *Space Habitats* simplifies the problem through an easily parsed set of cause-and-effect player actions that leverage the non-authoritative nature of games in two significant ways:

1. While there are consequences for failing to create the environments alien pets need, those penalties are far less severe than they would be if a student failed to care for a pet in the real world. The non-serious nature of the game allows players to focus on matching animal characteristics to the correct environment, rather than spiraling into a real-world discussion about stewardship of the natural world.

2. The other-worldly theming encourages players to question which aspects of their experience has direct correlation with the real world and which ones are embellishments created for the sake of gameplay. This may peak students' natural curiosity and provide teachers with a set of conversation starters they can use to unpack and discuss the game's content.

Introducing New Topics

Game-based programs support systemic thinking, dynamic concept modeling, and an approachable rhetorical tone, making them a natural fit for use at the start of a new unit. The player-driven nature of a play-based experience makes it an ideal tool for meeting STEM students where they

are in terms of skills and knowledge and providing next-level instruction that is relevant and motivating.

This use of video games as preparation for future learning was formally documented by Dylan Arena as part of his Stanford University PhD thesis. In his study, he delivered a WWII academic content lecture to three groups of students: one non-game playing control group, a group that played a fast-paced World War 2-themed action game (*Call of Duty 2*) and another group that played a turn-based "world building" game (*Civilization 4*).

After the lessons, each of the groups in the study took a formal multiple-choice assessment. Results showed that the game-playing groups had a statistically significant improvement overall--equivalent to roughly half a letter grade. Furthermore, each game-playing group delivered more nuanced responses on two open-response questions.

The *Civilization 4* group delivered more sophisticated responses to a "nations-focused" question by naturally framing their response in terms of "resources," "defenses," "empires," and "alliances," all of which were key elements of their game. Simultaneously, those who played *Call of Duty* responded to the "battle-focused" questions using terms such as "weaponry," "terrain," "communication," and "objectives." Based on this, we can conclude that not only can games influence players' retention of facts and choices about what to learn, but that different gameplay mechanics support different instructional frameworks.

It's worth acknowledging that using games at the start of a new lesson, while beneficial, can feel like a risky move for instructors. Games, by nature of their interactivity, represent a lack of authorial control. Understandably, this lack of control could be perceived as an opportunity for misunderstandings to arise in student's content interpretations. However, with appropriate teacher facilitation, the open-ended nature of games serves as an accessible on-ramp for more advanced topics and concepts.

Summary

While games will never replace traditional instructional models in the STEM classroom, they have proven to provide an effective, non-linear approach to presenting abstract information. By allowing students to actively manipulate virtual environments and explore a range of possible outcomes, game-based learning programs can encourage the thoughtful inquiry, deep understanding, and meaningful discussion students need to fully grasp the dynamic nature of STEM content. Educators who are willing to integrate game-based learning in the classroom may find that they are better able to "tee-up" new material and bring their subject matter to life.

Learn more about our Science solutions. Visit mheonline.com
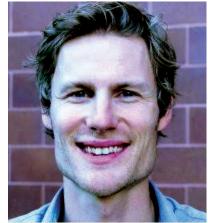
6

About the Authors

Matt Haselton

Matt Haselton is a Game Designer at Filament Games, and specializes in porting learning objectives into game mechanics. Prior to working at Filament, Matt was a designer at Quest Atlantis. Matt holds an M.S. in telecommunications from Indiana University – Bloomington, and a B.A. in English literature from Guilford College.

Dan Norton

Dan Norton is a founding partner of Filament Games and leads game design. Dan has designed games on a broad range of topics, ranging from marine turtle ecology to legal argumentation. His work has garnered multiple awards for its innovation and effectiveness, including the 2010 Joan Ganz Cooney Center's Developer Prize in the STEM Video Game Challenge.

Dan White

As CEO and Co-founder of Filament Games, Dan White wants learning to be associated with meaning and inspiration rather than accountability and drudgery. Accordingly, he believes that learning should be highly interactive, and that game-based learning, like project- and inquiry-based learning, is a "best practice" in the field of education. An alumnus of Cornell University and the University of Wisconsin-Madison, Dan has two primary passions: making outstanding learning games and building sustainable businesses.

References

Arena, Dylan. "Commercial Video Games as Preparation for Future Learning." LinkedIn SlideShare. June 26, 2012. Accessed September 01, 2017. https://www.slideshare.net/dylanarena/commercial-video-games-as-preparation-for-future-learning.

Gee, James Paul. *What video games have to teach us about learning and literacy.* Basingstoke: Palgrave Macmillan, 2008.

Toppo, Greg. *The game believes in you: how digital play can make our kids smarter.* New York: Palgrave Mac

Learn more about our Science solutions. Visit **mheonline.com**

SC17 M 12489   8