CHAPTER 6.

CONSERVATION OF MOMENTUM

BY CAMERON PITTMAN

Like most guys in their 20s and 30s, I grew up playing video games. One of my earliest memories takes place at a neighbor's house when I was about 4 years old. We were playing the original *Super Mario Bros.* game on NES and I remember loving everything about the experience of making a pixelated Mario jump across the screen. Not much has changed since then.

After I graduated from college with a degree in physics and astronomy, I taught high school science for four years (see Figure 1). During my last two years I tried and finally succeeded in teaching physics with a popular commercial video game called *Portal 2,* merging my favorite studies with one of my favorite pastimes.

Figure 1. Cameron helps his physics students build levels.

This chapter is not an in-depth look at *how* I taught physics with *Portal 2,* as that has already been described in quite a bit of detail in a journal article and on my blog physicswithportals.com (see

Notes).[1] Rather, I will focus on how I've applied my teaching philosophy to my classrooms and my career. I'll walk you through the choices I made as I planned for and implemented a curriculum using technology that is normally not considered educational.

In Part 1 of this chapter, I'll describe how I came to the decision to teach with *Portal* and my overarching philosophy toward using it as a virtual lab tool. But I couldn't do it alone. In the second part, I'll explain how I found support for my classroom from everyone involved—from students to parents, teachers, administration, *Portal*'s developer, Valve, and the gaming community at large. In the third part, I'll touch on the theme of failure in experimentation and how learning from failure has played such a large role in my professional adventure and my students' labs.

In the end, I hope you'll see that creating new teaching tools is simply fun for everyone involved, and that trying to build something new can be a reward in and of itself.

PART 1: WHY TEACH WITH VIDEO GAMES?

At the end of my second year of teaching in 2011, I started daydreaming about a classroom with a free-form virtual physics lab. I was working in Nashville, Tennessee, in a high-needs high school with insufficient lab equipment and an ordering process so bogged down by bureaucratic nonsense that it would realistically take at least a year to acquire any new lab supplies. I wanted a way to make it easy for my students to experiment with new ideas. As an avid gamer, I came to the realization that the cheapest, most powerful, and most accessible physics simulations came with names such as *Crysis*, *Halo*, *Battlefield,* and *Portal*. At the cores of ultrarealistic modern video games like these stand physics engines that calculate the way in-game objects should move and behave. As game makers continue to profit from games that look and feel realistic, they strive to build physics engines that more realistically reflect the real world (see Figure 2).

1. See Teaching With Portals: the Intersection of Video Games and Physics Education at http://www.learninglandscapes.ca/images/documents/ll-no12/pittman.pdf and my blog at http://physicswithportals.com.

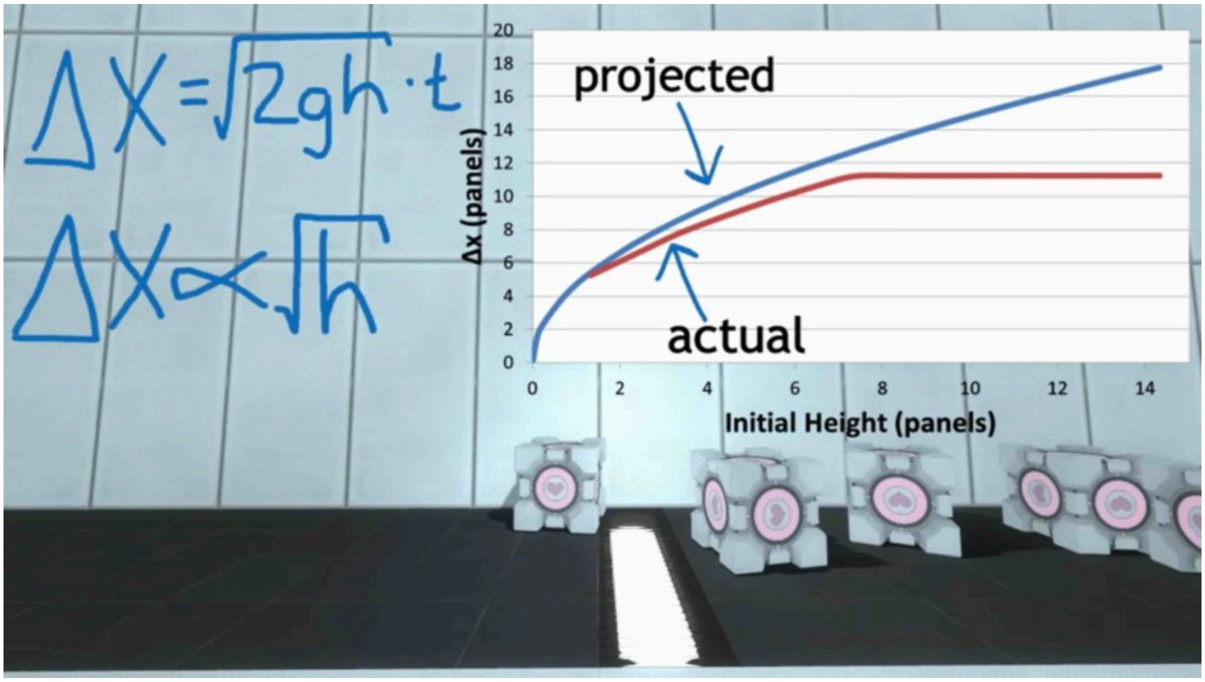

Figure 2. A graph from a physics experiment in which cubes were flung from a portal on a wall at different velocities (because they were originally dropped from different heights). The actual versus expected graph demonstrates the difference between how far from the wall the cubes would land in the real world versus how far away they landed in the game.

I quickly decided to write a curriculum that made the PC game *Portal* the centerpiece of a virtual physics lab curriculum. I choose *Portal* for a few reasons—the lack of violence, the ease of getting copies, and the low technical specifications.[2] As a bonus, the story has a science-y theme and it is extremely well regarded for its quality within the gaming community.

I battled district administration throughout my entire third year of teaching for the ability to install *Portal* on school computers. Eventually I moved to a new position at a charter high school and found some help from Valve, the developers of *Portal.* In my fourth year of teaching I finally implemented a semester of labs using *Portal*'s sequel, *Portal 2.*[3]

To understand how I taught with *Portal 2,* let's talk about how the game is played. *Portal 2* is a puzzle game. The game consists of a series of rooms (called "test chambers"), whereupon entering a room, you simply try to reach the exit. You play from the first-person perspective.

At a glance the game looks like a violent first-person shooter. The player clearly has some kind of gun in front of her. But this gun doesn't shoot bullets. It's called the portal gun for the obvious reason that it creates portals. There are two portals—an orange one and a blue one. The orange and blue portals are essentially wormholes. When an object enters one, it instantaneously exits the other (see Figure 3). The player uses the portal gun to place portals on various surfaces around the puzzle, spatially

2. The term technical specifications refers to the minimum requirements for computer performance needed to install and use a piece of software.
3. To learn more about exactly how I taught physics with a video game, check out the in-depth article I wrote for LEARNing Landscapes documenting my approach: http://www.learninglandscapes.ca/images/documents/ll-no12/pittman.pdf. And check out my blog, Physics With Portals at http://physicswithportals.com.

connecting disparate areas of the level in order to overcome obstacles that would be impossible otherwise.

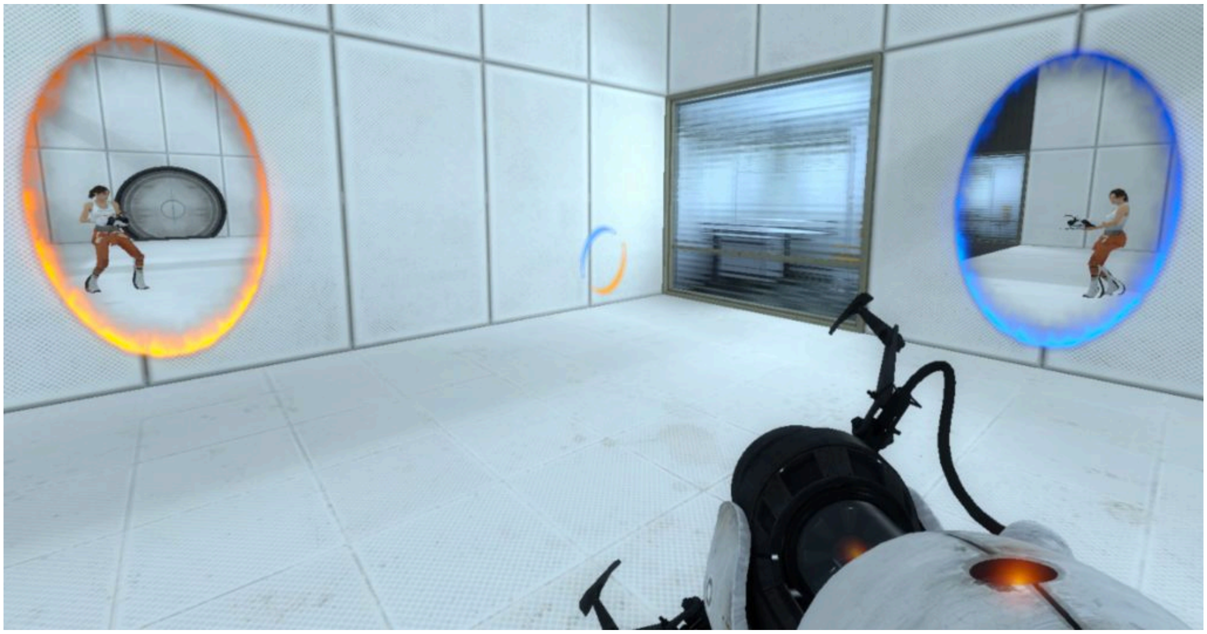

Figure 3. In this image you can see two connected portals—one orange, one blue—and the portal gun in the foreground. Notice that you can also see the player herself through the portals, as looking in one portal allows the player to look out the other.

The video *Portal 2 E3 2010 Gameplay Trailer* demonstrates the basic gameplay alongside a few different gameplay mechanics, such as excursion funnels (also known as tractor beams), aerial faith plates (also known as launchers), and laser puzzles.[4]

As it is a puzzle game, the amount of time a player can spend playing *Portal* is essentially a function of the number of puzzles. But each puzzle needs to be built by hand. There are a finite number of people at Valve who make puzzles and they have finite amounts of time. So, in order to create new value for the game, Valve created the Puzzle Maker, which makes it incredible easy for players to create and share custom puzzles (see Figure 4). It's easy enough such that someone with limited technical expertise, and even limited experience playing the game, can still create his or her first custom puzzle in a matter of minutes.

4. https://www.youtube.com/watch?v=JZD17pQSqUU

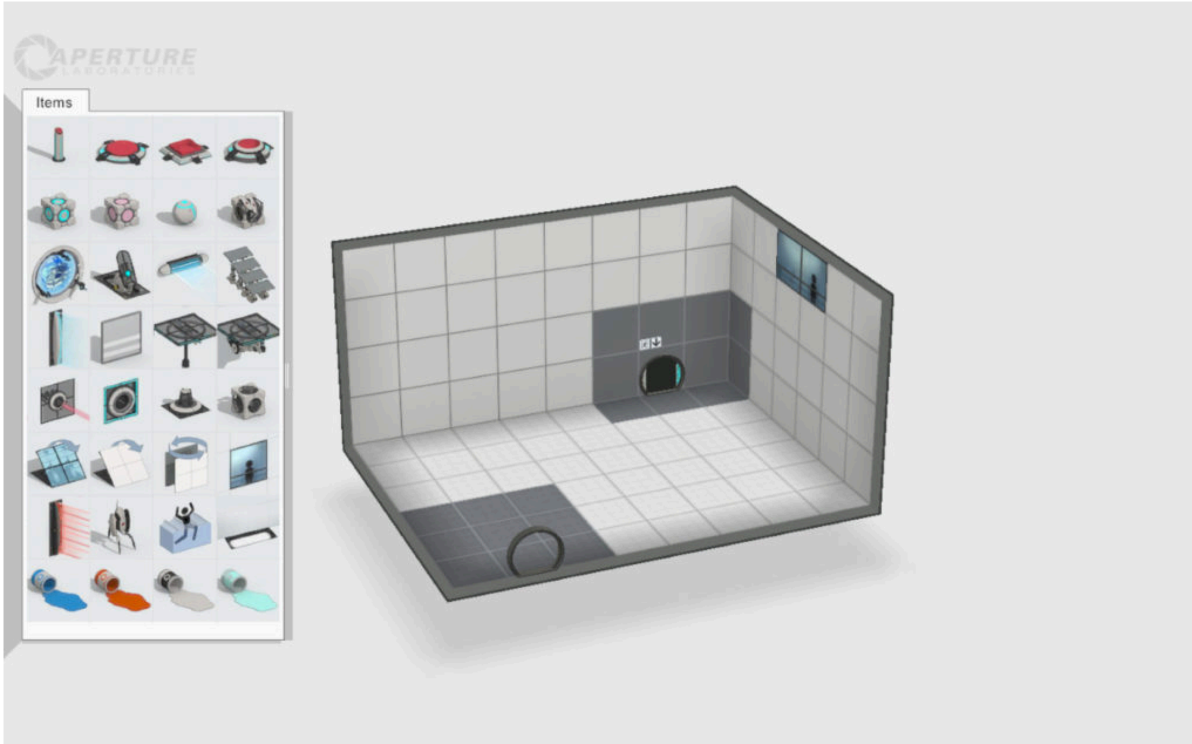

Figure 4. A typical view of the Portal 2 Puzzle Maker. Players add elements to the room by simply clicking and dragging them from the panel on the left.

So, let's go over the two main features *Portal 2* offers. It has a realistic physics engine and it has a mechanism to quickly create custom physical environments. You know what that sounds like to me? A full-blown, fully interactive physics simulator in a format palatable for a classroom.

My students treated *Portal 2* like a virtual lab by building experiments with the Puzzle Maker, hopping into the game, running their experiments, and collecting data. Using tools built into the game itself to measure distance, time, and mass, my students could collect enough data to answer pretty much any question from classical mechanics (the study of how and why objects move). I had my students building machines that launched objects with different forces, analyzing the trajectory of projectiles, creating infinite loops to measure terminal velocity, predicting the results of elastic and inelastic collisions, and even simulating thermodynamics.[5] It felt as if I were putting kids in the *Matrix* and letting them run wild trying to answer interesting physics questions.

It was pretty cool.

Beyond physics, video games in the classroom prepare students to succeed in the 21st century. The simple act of getting things done on a computer and troubleshooting when something inevitably goes wrong helps students practice the skills required to use technology in the modern workplace. (Here's a short list of things that went wrong during *Portal 2*: Games crash for no apparent reason, Steam, the platform used to launch *Portal 2,* loads halfway and stops without ever telling the user something is wrong, this weird glitch in which the menu in *Portal 2* shows up with only "NO STEAM" and "QUIT,"

5. http://physicswithportals.com/2012/06/26/ideal-gas-law/

levels that don't save, students who prefer a trackpad to a physical mouse, and Steam accounts that randomly log themselves out and crash the game.)[6]

My students were forced to work around new problems, such as installing Xbox 360 controller drivers, game progress that couldn't be saved, using the game's developer console to modify the environment, as well as figuring out how to fix or work around bugs. Given the number of people using computers at work, it makes sense for schools to purposefully teach students to work through minor issues with computers. Loading and playing *Portal 2* was a fun opportunity to teach some basic computer troubleshooting techniques alongside physics.

PART 2: HELP! IS ANYONE OUT THERE?

Teaching with a video game meant that I needed to collect enough copies of the game for my classroom. And games are not free. After writing a series of lesson plans describing how my students could experiment with the physics of various scenes in the game, I went to the Internet to ask for help.

Luckily, Valve tends to treat *Portal* as a giveaway. It was free for a number of years and routinely sells at $5 a copy or as part of bundles with other games. I already had an extra copy of the game and I knew that other gamers did too. So I took to r/gaming (reddit.com/r/gaming), an online community on reddit devoted to all things gaming, and asked for extra copies of the game.[7] I explained who I was and shared my lesson plans with the community. Within two days redditors (the denizens of reddit) were kind enough to share more than 20 copies of *Portal* with my classroom.

At the same time I emailed Valve, because why not? I had nothing to lose but the few minutes I spent typing. A little bit of research revealed that the company had an education-outreach email address, which seemed a pretty obvious recipient.[8]

As I did with reddit, I explained who I was, shared my lesson plans, and asked for enough copies of *Portal* for my classroom.

Someone from Valve messaged me on reddit *and* responded to my email within a few days, which I did not expect to happen.

It is worth remembering that people like to help teachers. Everyone knows that classrooms frequently lack funds.[9]Reaching out to people beyond the walls of my classroom made my *Portal* lessons a success. Had I not gotten in touch with Valve or asked reddit for help, this story might not have happened. If you need help for your classroom, do some research to find people who have ample amounts of what you need and be as specific as possible when you ask for help.

During the months that followed my first email to Valve, I met some people within the organization who were interested in education. Leslie Redd, Valve's former education guru, took particular interest

6. Steam is what I call the "iTunes of video games." You have to load Portal from Steam.

7. The name reddit is always spelled with a lowercase r. For the letter to redditors, see https://www.reddit.com/r/gaming/comments/j88ft/rgaming_this_inner_city_high_school_physics/.

8. While I believe this email address, education@valvesoftware.com, is still active, Valve's education efforts have significantly diminished since my time as a teacher.

9. I highly recommend checking out Kickstarter (https://www.kickstarter.com) or Donors Choose (http://www.donorschoose.org/) if you need resources.

in my classroom. When we first got in touch, we discussed my school, my students, and my plans for labs with *Portal.* Within a few days she made sure I had as many copies of *Portal* and its sequel as I needed.

At that point I realized I had gotten what I wanted from Valve and, even if my next email or next request went unanswered, I was happy. Cold-emailing Valve had been a good idea.

In the summer of 2012, I changed schools and was hired to teach physics and chemistry at LEAD Academy, a new charter high school also in Nashville. During my interview with the school's administrators, I learned that LEAD had 30 new MacBook Pros on order. And the school's Internet was free of blocked ports. Before mid-August I had a classroom set of high-quality laptops with *Portal 2* installed and running smoothly.

At this point, I had convinced my colleagues that this was a good idea. I wasn't worried about my students' support, but I still needed parental support.

I organized a Physics Night for parents in my classroom at the beginning of the year (see Figure 5). With a lot of luck, I had at least one parent or guardian for all 30 of my physics students. I spent two hours explaining exactly why I wanted to use *Portal,* what this meant for their children, and answering questions. I also gave parents a chance to play.

Figure 5. Cameron and the parent of a physics student enjoying Physics Parents Night at LEAD Academy.

Afterward, I had nothing but support from parents throughout the semester.

Without support from Valve, the Internet, LEAD's administration, my students, and their parents, *Portal 2* never would have become a virtual physics laboratory. If you are fearful of reaching out for help, remember that the worst anyone can say is "no," which actually isn't a big deal. You've got nothing to lose. So, try again.

PART 3: TRY, FAIL, LEARN, TRY AGAIN

My life has changed quite a bit since I finished teaching with *Portal 2* in 2013. Since leaving my high school classroom, I became the director of content for a website, taught myself how to code, became a software engineer, and eventually joined Udacity. Now I make websites and create courses that teach people to develop modern websites that look cool and do cool things.

I am in an existential crisis with a course I am developing at the time of this writing (which will have been released well before the book you are reading is published). I desperately want to be proud of it but the only thing I notice when I review my work is that I need to do a better job of looking natural on camera. I look so awkward. (Why am I standing there in a Superman pose for the whole course!?) I half want to delay the release of the class to reshoot scenes plagued by my wooden acting. What's worse, the course's learning curve holds potential pitfalls for novice students.

But I have had an epiphany, too. People who make awesome things always, always start by making something awful first. Perfection takes practice. It takes mistakes and missteps. But, most important, perfection happens when you learn from imperfection. So I can be happy about releasing an imperfect course because it gives me the opportunity to learn and inch a little closer to perfection in my next one.

Video games are learning experiences. They embrace imperfection and invite players to fail and learn from their mistakes.

You cannot lose in *Portal 2*. Dying is the worst thing that can happen to you in the game, but when you die you simply respawn at the beginning of the puzzle, ready to tackle the challenge with newfound knowledge of what won't work. Players are invited to try new strategies to beat levels. I invited my high school students to do the same thing. They were building experiments inside the game. And their experimental apparatuses failed constantly. I taught them to recognize their mistakes, go back to the Puzzle Maker, make some changes, and try again. No harm, no foul.

Mastering puzzles and running experiments (virtual or physical) necessitates trial and error. The same held true for my lesson plans.

I designed an experiment investigating terminal velocity in which students were to set up an infinite loop. When two portals are vertically aligned, meaning one is directly above and facing the other, objects repeatedly fall out of the first portal, fall into the second, and then fall out of the first portal again. Hence, objects fall forever in an infinite loop (see Figure 6). In the experiment, students were to measure the time it took an object to fall an arbitrary number of loops at various heights. By comparing the time it took objects to loop through the portals, students could calculate how fast they were falling and get an estimate of the maximum velocity an object falling through air can obtain, which scientists call *terminal velocity.*

Figure 6. A midair cube falling in an infinite loop. Notice that the portals are directly on top of one another. As soon as the cube falls into the blue portal, it falls out of the orange portal in a never-ending cycle.

When students started presenting their findings at the end of class, I realized that I had made a huge mistake. If an object maintains conservation of momentum as it travels through portals, then it follows that the distance between portals should have no effect on terminal velocity. It might take an object a few more loops between two close portals to reach terminal velocity; nevertheless, it should still reach the *same* maximum velocity as an object falling through two distant portals.

Student data, however, indicated that as distance between the portals increased, so did terminal velocity. I had screwed up. The students helped me realize that portals in fact have a speed limit. So the law of conservation of momentum actually does *not* completely hold for objects traveling through portals and the basis of the lesson's showcase experiment was fatally flawed. Whoops.

After the lab and in my later class, I challenged students to instead prove why that experiment was a poor method to find terminal velocity. I wanted to turn a mistake into a learning experience for everyone involved.

Incidentally, the act of demonstrating that portals failed to follow the law of conservation of momentum requires an understanding of physics at least equal to, if not deeper than, the knowledge needed to run a lab on conservation of momentum with accurate physics. If I find myself teaching with *Portal 2* again, I would actually try to incorporate lessons in which students disprove the physics of the game. I might even make the same "mistake" again and let them try to catch it. Learning from failure, even a teacher's failure to vet a lesson, creates big impacts.

Don't be afraid to fail. Learning happens through failure. The only way to create something amazing is by experimenting with a lot of awful ideas first.

CONCLUSION

Before I could teach with *Portal,* I had to install it on 25 laptops. This was an interesting problem. First off, the game is massive, requiring about 10 gigabytes of space. On a broadband Internet connection, it might take anywhere from a few minutes to a few hours to download one copy. I needed 25. Downloading the same massive file 25 times is simply unreasonable on a high school's Internet connection.

You're probably wondering if you can just copy and paste the same game on 25 different computers and get all of them to work. As it turns out, you can, but it's tricky.

Portal 2 has to be launched from Steam. On Steam, every game has to be attached to an account. So what I really got from Valve was 25 different accounts, each with a copy of *Portal 2* attached. In order to copy and paste the game onto a new computer and expect it to work, you have to follow a short set of steps that need to be completed in the right order; otherwise Steam would fail to recognize that the game was already installed.

To get everything ready, I needed to install Steam, paste a copy of *Portal 2* in the right location, log in to Steam with the right account info, check to make sure the game existed and that it loaded bug free. And I needed to do that 25 times.

I had the added bonus of needing to finish in two days, which meant a total of two planning periods (180 minutes total) to complete the whole process. I figured out a neat little conveyor belt with which, if I timed all of my actions right, I could work on five laptops at once, each at a different stage in the install process. I had a blast making sure I was always busy and never pausing to wait for some long operation to finish.

I love big projects because they are made up of little problems. Every step along the way is a chance to win a little victory. Teaching with *Portal 2* took so much time and energy, but every little victory reinforced the fact that, above all else, creating a new teaching tool is just fun.

If you have an idea for something crazy in your own classroom, or if you want to improve your teaching tools, I want you to consider following the same general steps I took to teach with *Portal 2*:

1. Identify the problem (lab supplies are hard to get).
2. Identify a possible solution (*Portal 2* is a physics simulator that's easy to get).
3. Rally support from everyone involved and reach out for help. (Thanks, reddit and Valve!)
4. Realize that the worst thing you can do is nothing. Failure is a good thing because you can learn and try again.

The real lesson here, I think, is not that *Portal* is a fantastic teaching tool (even though I think it is). Rather, improving a classroom is just like any other problem. I want you to apply creativity and persistence to surprise yourself with your capacity to create a better way to teach. The world is simply changing too quickly to continue teaching the same way year after year. Have some fun and give your students the opportunity to have fun as they start to understand the world around them in new ways.