# “Tailwind: Creating a Teacher-Friendly Game for Vector Mathematics”

THESIS

Submitted in Partial Fulfillment of
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by

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# VITA

Alexandros Lotsos was born in Athens, Greece in September 6th, 1994. Graduating High-school and the International Baccalaureate program from Geitonas School in Athens, he moved on to complete his undergraduate studies in mathematics and philosophy as part of Boston University's class of 2016.

His love for technology and programming would lead him to New York University where he would pursue his master's degree in integrated digital media, focusing on creative coding and game development. His passion for the education of mathematics was the driving force of this project.

## ACKNOWLEDGMENTS

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This project would not have been possible without you!

# DEDICATION

I would like to dedicate this thesis project to my family who supported me through all my studies, even though they probably had no idea what I was doing for the most part. I wouldn’t have made it this far without you.

# ABSTRACT

“Tailwind: Creating a Teacher-Friendly Game for Vector Mathematics”

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Alexandros Nikolaos Lotsos

Advisor: Ramsey Nasser

Submitted in Partial Fulfillment of the Requirements for

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The purpose of this project is to develop and test the first iteration of an educational game, called Tailwind, a 3D platformer built using the Unity3D engine. The game aims to aid in the teaching of Euclidean vector mathematics in a high school setting and is designed to complement traditional teaching methods, rather than to serve as a means to redesign them. Through an understanding of game-based learning, games and their learning principles, as well as the established methods for educational game design we have identified three key factors that seem to be integral to the success of an educational game: relevance, effectiveness, and usability. Surveys providing data regarding teacher’s game use in the modern classroom seem to indicate that the usability

of modern educational games is lacking. Tailwind would thus focus on being an effective educational game purely via good gameplay principles and the seamless incorporation of examples of vector mathematics. The game would provide additional affordances, such as a replay system, in an effort to make it more usable for teachers that would like to teach via the examples and gameplay that it provides. Tailwind underwent two iterations, the first of which was an alpha version meant to test the appeal of the core game mechanic, gliding, while the second one was meant to evaluate its educational effectiveness via the use of the RETAIN framework. Throughout both iterations, testers of the game who were also teachers provided qualitative feedback that was incorporated in the design of the replay system, as well as in the discussion of future iterations for Tailwind.

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# INTRODUCTION

The efficacy of game-based learning is a topic that has been debated and researched for many years, with the main question being focused on the *effectiveness* of games as a means for learning. With recent publications by giants of the field providing ample theoretical and research-based evidence, there is very little doubt that, under the right circumstances, games can provide great benefits to a variety of different learners (Bartle et al., 2010; Gee, n.d.; Plass, Homer, & Kinzer, 2015). Having come a long way since the days of *Math Blaster* and *Number Muncher*, educational games are evolving rapidly and are making great pedagogical strides. Titles like *Little Big Planet, Minecraft* and *Lure of the Labyrinth* are providing increasingly rich, complex, and multilayered learning experiences through which students can immerse, express, and cultivate themselves, while also joyfully engaging with some of the most potent learning devices that the 21st century classroom has to offer.

However, during all this discussion regarding the effectiveness of games as learning devices, there is very little mention of the teachers who are introducing these games into their classrooms. Organizations like *The Institute of* Play and the *Games for Learning Institute* have started considering what a curriculum that would revolve around games would look like. Pushing towards a redesigning of teaching practices and exploring new territories in the intersection of education and play is certainly exciting, but is there room for a different approach? Is there such a thing as an effective learning game that would serve to complement and enhance traditional teaching methods? What would that game look like? And how would it measure up to the newer, more decorated educational titles of recent years? The purpose of this project is to attempt to tackle all of those questions via the creation of a game called Tailwind; a 3D platformer with the objective to aid in the teaching of Euclidean vector mathematics in high school classrooms.

## BACKGROUND

To further understand the rationale behind the creation of Tailwind and its prescribed role in the classroom, there are some theoretical bases that need to be covered. We will provide an accepted definition of game-based learning and make clear the distinction between game-based learning and gamification- two terms often confused for each other. This will lead to a discussion of existing methods for designing educational games and the necessary conditions for a game to be deemed appropriate for use in a real classroom environment. Finally, we will look at several surveys that concern the uses and roles of video games in modern classrooms, by modern teachers. By the end of this background section, readers will have a sufficient understanding of the foundations of game-based learning and the ecosystem surrounding games in education.

For the purposes of this paper we will be working with a definition of game-based learning that is agreed upon by two of the most prolific figures of the field: Jan Plass and James Paul Gee. In his article, “Foundations of Game-Based Learning”, Plass defines game-based learning as “a type of game play with defined learning outcomes”, while also stating that it is not a necessity for game-based learning to be accommodated by a digital game(Plass et al., 2015). Digital or not, it is important to distinguish between gamification and game-based learning as they are rooted in different theoretical principles and result in drastically different outcomes.

For reference, one of the first definitions of gamification stresses the fact that it involves the “use of game design elements in non-game contexts” and was proposed by Sebastian Deterding (Deterding, Dixon, Khaled, & Nacke, n.d.). The difference between game-based learning and gamification of education should thus become clear in the sense that the former aims to facilitate learning through purposefully designed game play, while the latter aims to superimpose playful elements onto already established learning processes to make them more attractive. Plass elaborates on this distinction by considering the gamification of math homework, stating that it would involve “giving learners points and stars for the completion of activities that they consider boring”(Plass et al., 2015). On the other hand, exploring the same math topic through game-based learning “would involve redesigning the homework activities, using artificial conflict and rules of play, to make them more interesting and engaging” (Plass et al., 2015).

Arguments for the efficacy of game-based learning vary in form and complexity but a unique line of thought is proposed by Gee in his book, “Good Videogames and Good Learning”. Gee recognizes the fact that most of the accepted ‘good’ video games are “long, complex, and difficult, especially for beginners” (Gee, 2013) but then asks the question of how game designers manage to get players to play their games. His answer to this question is that somehow, through necessity, game designers of good games “have hit on profoundly good methods of getting people to learn and to enjoy learning" (Gee, 2013). That is, Gee is considering the elements of gameplay that make games good learning devices.

Even on a surface level, this line of thought makes perfect sense. To play and enjoy most games, players need to understand (or learn) the rules, mechanics, and goals of the game. If a player does not understand the rules, mechanics, and goals of the game, then the player will not play the game. If a game is not played, then the designers will not make money. Therefore, game designers *had* to come up with ways for players to effectively and pleasantly learn their games, which is why Gee believes that good games promote good learning. Gee analyzes several principles that he deems "good learning principles", as he identifies them in well-known 'good' games of the time. He separates them into three categories that he lists as "Empowered learners", "Problem Solving", and "Understanding" and states that "the stronger any game is on more of the features on the list, the better its score for learning" (Gee, 2013). It is worth noting at this point, that Gee does not believe that these principles are unique to games, rather they are good learning principles that are present in games and should be observed and acknowledged.

The first category of "empowered learners", aptly named, focuses on learning properties found in games which make the player feel important, able, and encouraged to be proactive about their education. **Co-design** stresses that learners "feel like active agents (producers) not just passive recipients (consumers)" (Gee, 2013). In terms of gameplay, this element refers to how good games make player decisions feel meaningful and impactful, thus making players "feel that their actions and decisions … are co-creating the world they are in" (Gee, 2013). This notion is easily transferable to an educational context and refers to the sense of agency that learners in good environments feel. Like a player's actions co-shaping the game world they are part of, Gee states that the "curriculum should be shaped by the learners' actions and react back on the learners in meaningful ways" (Gee, 2013).

**Customization** refers to the *opportunities* that learners are given to impact their education, specifically through being able to "make decisions about how their learning will work" (Gee, 2013). Good games achieve effective customization by allowing players to be effective via different styles of gameplay while also not punishing them severely for preferring a different style. This draws a direct parallel to education by linking styles of gameplay to learning styles. Gee states that customization in classrooms "would allow students to discover their favored learning styles and to try new ones without fear" (Gee, 2013).

**Identity** builds on the fact that "deep learning requires an extended commitment" and that such a commitment is made easier via a cultivated sense of identity (Gee, 2013). In good games, this commitment is facilitated either through well-written and deep characters, or characters that are blank and customizable so that the player can project their own personality onto them. In education, a sense of identity becomes important when one realizes that academic disciplines are activities rather than bodies of facts, and that it is more important for a learner to feel like "a scientist doing science" than a learner memorizing a list of facts (Gee, 2013). According to Gee, if a learner values an identity, then the facts will come as a natural means to support that identity.

Finally, the concept of **manipulation and distributed knowledge** refers to the value of “fine-grained action at a distance” which, according to Gee, causes humans to “feel as if their bodies and minds have stretched into a new space” (Gee, 2013). In general, this refers to the sense of empowerment that learners experience when they have smart tools that “extend their area of effectiveness” at their disposal (Gee, 2013). Good games accomplish this by embedding expertise and complicated functions into their characters, interfaces, and other means of control that a player might have. In this way, the player of a game like *Tomb Raider* can depend on the main character *Lara Croft* to know how to climb, leap and scale through the environment around her so that the player can focus on other aspects of gameplay that contribute to the immersion and enjoyment of the game. Therefore, supplying learners with smart tools that internalize complex functionalities can allow them to explore more relevant parts of different disciplines without having to worry about all the different little things unless they need to.

The second category of “problem solving” focuses on the order, layout, and character of the content in the learning process. Players need to feel like they are part of an effective, thought out process that is setting them up for success rather than failure. Having **well-ordered problems** that are **pleasantly frustrating** can help keep the attention of players, while also making sure that they will be well-equipped to handle tougher challenges down the line. According to Gee, immediately throwing players in the deep end may result in “creative solutions” that would work for a given problem but might not work for simpler problems. Gee refers to this as leading them down a “garden path” (Gee, 2013). This may make it difficult to properly adjust the difficulty of games and learning, and thus, players might feel like they are either not getting challenged enough, or that things are *too* challenging. Good games will either use well-ordered problems to put players in a pleasantly frustrating zone throughout the whole game, or they will properly adjust difficulty on the fly such that the level of challenge is appropriate at any time for a given player. The former is harder to translate into education given that learners tend to be very different from one another, so the importance of appropriate feedback and adjustability is even more crucial in a learning context.

A good learning environment, can be taken one step further by ensuring that information and instructions are presented and used **on-demand** and **just in time**. According to Gee, verbal information is difficult for people to digest and use “when given lots of it out of context and before they can see how it applies in actual situations”, thus presenting it at an appropriate time and manner is essential. Good games will tend to give players information that they need, when they need it; neither sooner, nor later. Trying to imagine a videogame that is only ever playable after the player has read the manual should be enough to understand why information is very often mismanaged in a traditional educational context. Learners are often expected not to act until they have read and reading before acting tends be much less effective because of the lack of context and situation. Gee perfectly sums it up when he states that “game manuals, just like science textbooks, make little sense if one tries to read them before having played the game” (Gee, 2013).

Well-ordered and pleasantly frustrating problems, supported by proper information management, can thus be used to facilitate **cycles of expertise** with Gee arguing that the cycle of expertise is “the very basis of expertise in any area” (Gee, 2013). A cycle of expertise refers to the practicing of skills until they become “nearly automatic”, or otherwise internalized, and then “having those skills fail in ways that cause learners to have to thing again and learn anew” (Gee, 2013). Good games have the player learn a set of skills via different levels in the game and often challenges them with a boss that forces them to use those skills efficiently. When the player moves on to a different level, the learning process begins again and repeats itself. Unfortunately, according to Gee, this does not tend to happen in an educational context, or may happen *too* often, but he posits that the cycle of learning, internalizing, challenging, and expanding could prepare learners to “learn how to manage their own life-long learning and to become skilled at learning to learn” (Gee, 2013).

Good games will also often utilize **fish tanks** and **sandboxes** as alternatives to normal level-by-level gameplay to construct effective tutorials and help players understand the game “as a system”, as well as to encourage exploration of game interactions and mechanics (Gee, 2013). The term “fish tank” specifically refer to a “simplified eco-system that clearly displays some critical variables and their interactions” while, a sandbox refers to a situation that *feels* like the real thing but lacks the consequences that a real portion of gameplay would have (Gee, 2013). These concepts are missing from traditional education and would be of very much help given that school has wrongly been made “too risky and punishing” and fails to help students understand and accept the fact that “the real world is a complex place” (Gee, 2013).

The overarching theme of the properties in the “problem-solving” section of Gee’s list is that good games offer their players an opportunity to develop the appropriate skills and react to challenges in an effective way by using those skills. The unifying, key element that brings all these skills together and keeps players engaged is that the player is made aware that they must use their **skills as strategies** so that they can succeed in the game. In other words, good games will effectively situate and contextualize all the skills the player is learning in the different tutorials and levels. Very often, in traditional education, learners will question *why* they are learning something and wonder if they will ever actually *use* the facts they are learning. Gee asserts that “people learn and practice skills best when they see a set of related skills as a strategy to accomplish goals they want to accomplish”, and unfortunately this is a cue that traditional education has not yet taken fully[1].

Every concept that Gee has highlighted in the first two sections somehow relates to the way games can empower their players and encourage them to participate in a well-structured, effective, and situated learning process. This can be taken one step further with the two last concepts that Gee identifies in the

[1] This has changed in recent years with the advent of project-based learning and inquiry based learning, especially in STEM classrooms.

“understanding” section, namely that games promote **system thinking** and take meaningful actions even further by using **meaning as action image**. According to Gee, understanding that their skills will apply to a specific task is not sufficient for good learning and good gameplay. Instead, he posits that “people learn skills, strategies and ideas best when they see how they fit into an overall larger system to which they give meaning” and that good games allow players to understand “how each of the elements in the game fits into the overall system of the game *and its genre*” (Gee, 2013). Thus, what Gee refers to as system thinking, is the ability that games have, to teach *transferable* skills (from game to game) as the players move throughout a genre. On the other hand, what Gee refers to when he talks about meaning as action image is the tendency that games have, to situate the meaning of their instructions and terms into imagery that is relevant to games that players play. In a lot of ways, the system thinking principle is a systemic extension of the skills as strategies principle, while the meaning as action image principle is an extension of the information management principle in the previous section.

As a reminder, Gee identifies these principles to highlight why games are good at making their players learn the games themselves. Games employ good learning principles so that players can learn how to play the game -and possibly other similar games. What Gee has *not* done, however, is extend these principles to the issue of what constitutes effective game-based learning in a classroom context. Thankfully, there have been several frameworks proposed that seek to do exactly that, and we will examine two of the most prominent ones: the

RETAIN[2] model, and the four-dimensional framework. In later sections, we will also be using these frameworks as a means of brainstorming and evaluating Tailwind.

The four-dimensional framework proposed by de Freitas and Oliver, identifies four distinct but related elements that have a very similar purpose to the RETAIN model. It was conceived as a tool to help in the evaluation of educational games and by extension, to help educators select and use the right games in their classrooms, as well as to help developers produce appropriate educational games (de Freitas & Oliver, 2006). The four dimensions of the framework are **context, learner specification, mode of representation,** and **pedagogic considerations** and it is very much highlighted that these dimensions *cannot* be considered separately.

The **context** dimension covers, in a broad sense, the space in which the learning happens. From macro-level, sociopolitical and economic factors, to micro-level factors like the resources, expertise and aptitude of the educator using the game (de Freitas & Oliver, 2006). Next, the **learner specification**, dimension is meant to highlight the characteristics of the group of learners that will be using the game, including basic information like their age and grade level, as well as more complex and specialized information like learning styles and preferences(de Freitas & Oliver, 2006). The third dimension of **mode of representation** focuses on the technical and representational aspects of the game itself. In a lot of ways this dimension takes into consideration the level of immersion that the game affords, both inside the game world, and while reflecting

[2] RETAIN here stands for: **R**elevance, **E**mbedding, **T**ransfer, **A**daption, **I**mmersion and **N**aturalization

on gameplay. Finally, the **pedagogic considerations** dimension focuses on the processes of learning that take place in and around the game. Educators are meant to consider the effects on learning that the game has, as well as the activities that they design around it. Below is an illustration of the framework that highlights the interconnectedness of the dimensions proposed.

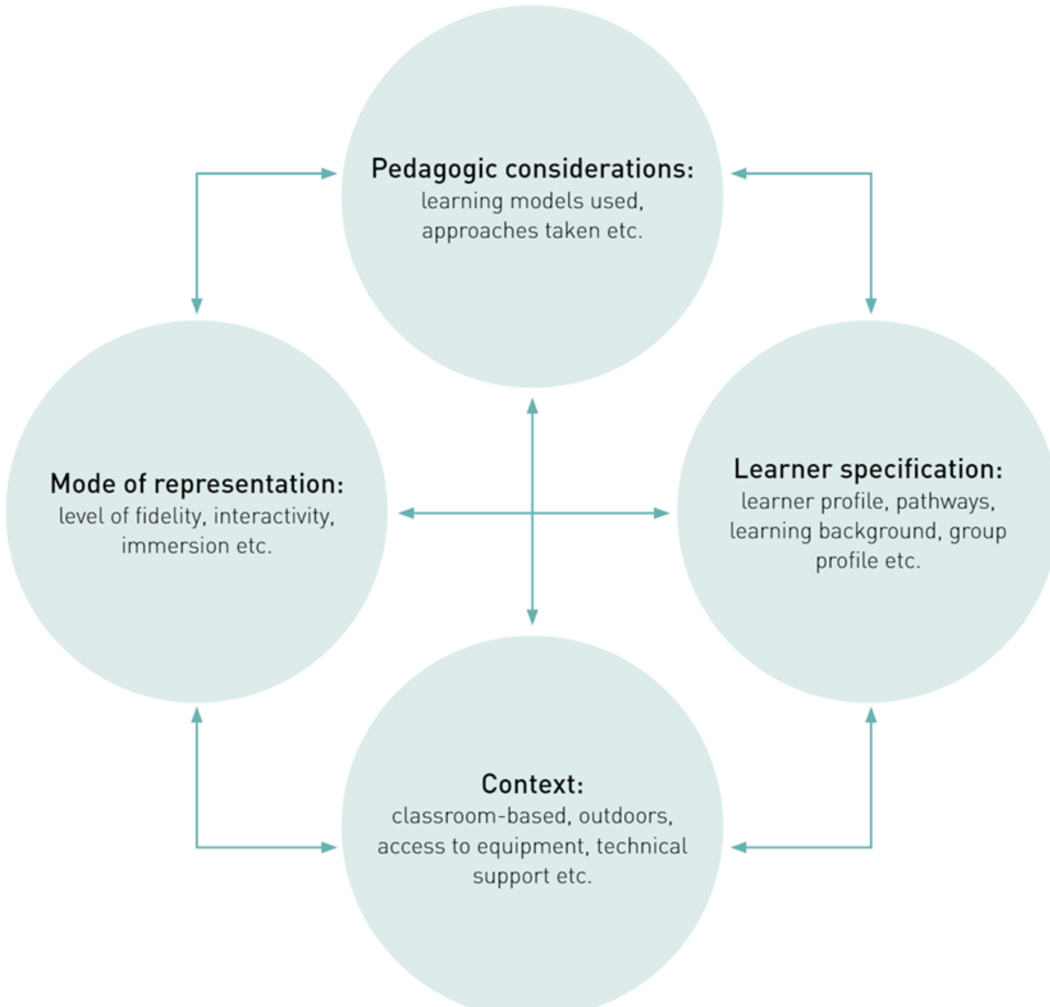


*Figure 1: Illustration of the four-dimensional framework* (Bartle et al., 2010)

In order to use the four-dimensional framework, educators and developers are supposed to ask questions relating to each of the dimensions in an iterative manner. For example, a broad starting question regarding the context dimension might simply be “What context are we considering?”, followed by questions in the other dimensions such as “Who are the learners?”, and “Which pedagogic models and approaches are being used?”. This would eventually continue until all the dimensions have been exhausted and the process would start again from the original dimension (in our case, the context). The next step would be to ask a more detailed question and complete another cycle; rinse and repeat. (For a checklist of questions proposed by de Freitas and Oliver, see Appendix A).

The RETAIN model, proposed by Gunter et al, was created with the purpose of helping educators choose appropriate educational games that incorporate academic content appropriately, promote the transfer of knowledge, and encourage the practicing of content such that learners will effectively internalize and reuse what they learn (Gunter, Kenny, & Vick, 2008). Each of the six elements has a distinct purpose in helping educators identify appropriate educational games for their classroom, but it can also be presented as an aide to game developers so that they can use it to guide the design of their games. Below is a table that lists and briefly defines the different elements of the RETAIN model (For complete definitions and a rubric see appendix B).

| Table 1: Required aspects for appropriate serious games | |
|---|---|
| **Relevance** | i) presenting materials in a way relevant to learners, their needs, and their learning styles, and<br>ii) ensuring the instructional units are relevant to one another so that the elements link together and build upon previous work |
| **Embedding** | assessing how closely the academic content is coupled with the fantasy/story content where fantasy refers to the narrative structure, storylines, player experience, dramatic structure, fictive elements, etc |
| **Transfer** | how the player can use previous knowledge in other areas |
| **Adaption** | a change in behaviour as a consequence of transfer |
| **Immersion** | the player intellectually investing in the context of the game |
| **Naturalisation** | the development of habitual and spontaneous use of information derived within the game |

*Figure 2: Adapted Definitions of the Different Aspects of the RETAIN Framework* (Bartle et al., 2010)

To evaluate a game using the RETAIN model, the user is to give integer ratings, ranging from 0 to 3, for each one of the six elements which are then used to calculate a weighted sum that represents the total score of the game. The weights for each element are based on how important it is and are represented by increasing multipliers. This means that the least important element, relevance, would have a multiplier of 1, while the most important element, naturalization, would have a multiplier of 6. In general, the higher the score of a game, the more appropriate it is deemed for classroom use and thus, if a game is awarded a rating of 3 in every category, it will boast a maximum score 63 points.

Therefore, having understood the definition of game-based learning, having seen how games incorporate good learning principles, as well as how those good learning principles are *meant* to be leveraged in a classroom, we can come up with three necessary, but not sufficient, conditions for a game to be an effective learning tool:

1. The game must concern a valid subset of the curriculum (i.e. Does it concern a subject relevant to the ones already taught in the classroom?).
2. It effectively teaches that subject to a variety of learners (i.e. Is it applicable to learners of different learning styles and backgrounds?).
3. It is practical to use in a variety of classroom contexts (i.e. does it need extreme amounts of resources? Does it disrupt the normal flow of teaching?)

We can also verify the applicability of these conditions by looking at recent surveys of teachers and their opinions and habits of game use in US classrooms. We will be looking at two surveys in an effort to understand *how* and *why* teachers use games in the classroom, as well as what challenges they face in their efforts to use games during the learning process. The first survey is called Level-up Learning and was conducted by the Joan Ganz Cooney Center in 2014, while the second survey is a report on the A-Games project, conducted by the University of Michigan in collaboration with New York University in 2014. Interesting statistics will be presented in the following two tables with the first one containing data on game usage and methods (i.e. *how* and *why*). The second table will be highlighting the reported challenges and frustrations that teachers cited as barriers to using games in their classrooms across both surveys.

| **Level-up Learning**<br>*Takeuchi & Vaala, 2014*<br>*K-8 Teachers* | **A-Games Project**<br>*Fishman et al., 2015*<br>*K-12 Teachers* |
|---|---|
| **79%** of game using teachers use games **at least once a month**. **9%** use games daily. | **83%** of teachers **use** games at least once a month. **18% use games** daily**.** |
| Only **4%** believe that games are not effective in improving STEM learning | **80%** of teachers who are comfortable with using games in their teaching do so weekly or more often. |
| The most common use for games is teaching of supplemental content | The most common use of games is to cover content mandated by state/national or local/district standards |

*Table 1: Statistics on Game Usage in US Classrooms* (Fishman, Riconscente, Snider, Tsai, & Plass, 2015; Takeuchi & Vaala, 2014)

| **Level-up Learning**<br>*Takeuchi & Vaala, 2014*<br>*K-8 Teachers* | **A-Games Project**<br>*Fishman et al., 2015*<br>*K-12 Teachers* |
|---|---|
| **45%** of teachers reported **insufficient time and cost** as challenges when using games. | **53%** of teachers reported **insufficient time and cost of games software** as barriers to using games. |
| **30%** were not sure how to integrate games into their curriculum | **33%** were not sure how to integrate games into the curriculum |

*Table 2: Statistics on Barriers to Game-Based Learning in US Classrooms (Fishman et al., 2015; Takeuchi & Vaala, 2014)*

In summary, from table 1, we can see that teachers generally tend to make *some* use of games in the classroom, and that they generally believe that games are useful. Table 1 also tells us that games are being used to actually *teach* material, rather than as a break activity or for other miscellaneous purposes; the caveat being that the teachers of the first survey use it to teach supplemental material while the teachers of the second survey are more daring in their use of games. Finally, an interesting insight that comes from table 1 which is elaborated on in detail through the A-Games report, is that the level of comfort a teacher has with games, is a very good predictor of how likely that teacher is to use games (Fishman et al., 2015). From table 2 we see that most teachers believe that games take a significant amount of time and resources to effectively implement in the classroom. More importantly however, we see that a good percentage of teachers are unsure of how to effectively integrate the games at their disposal into the curriculum.

Therefore, if we assume that the educational games that teachers are making an effort to use in their classrooms have been built with any of the principles discussed in this chapter in mind, then the attempts that developers have been making at making *usable* games have only been moderately successful. Given that only around 4% of teachers believe that games are ineffective in improving STEM learning, the games are clearly effective when it comes to teaching a variety of concepts to a variety of learners. However, approximately half the teachers think that games are too costly, and that around a third of the teachers are unsure how games fit into their curriculum. Thus, when developing Tailwind, we will be following the established methods for making a game *effective,* but we will be trying some new things when it comes to making the game *usable*.

## TAILWIND: OVERVIEW

As a direct reaction to the statistics outlined above, Tailwind's educational purpose is to fit into and complement the teaching practices of modern teachers. This is meant to contrast the notion that game-based learning is somehow innately different, or more special, than regular learning. From the surveys above, educational games are more than effective at conveying material and are definitely sound from a pedagogical perspective. However, it seems to be the case that they demand severe alterations in teaching practice. This results in the game developers having to make sample lesson plans and instruction manuals to go with their games, which makes the process more complicated than it should be. A quick look at the resources provided alongside games like *Lure of the Labyrinth*, or any of the *BrainPOP* titles should serve as context for this statement. In the end, because of the overhead associated with these games, teachers often do not reap the benefits and they end up feeling like they don't know *how* to use games in their classroom.

In a lot of ways, Tailwind takes a different approach to game-based learning than most educational games. Keeping in mind the definition presented by Plass, Tailwind's learning outcome is not as clearly defined as the outcome of a game like *Math Blaster* or *Lure of the Labyrinth* and it would simply be incorrect to say that Tailwind aims to teach its players vector mathematics. Because Tailwind is meant to help teachers cover the basics of vector mathematics, the game must allow for variable learning outcomes. By placing learners in an environment full of *examples* of vector interactions and providing the teachers with features that let them highlight and dissect those interactions, Tailwind is designed to supplement the teaching of vectors, rather than redesign it.

The idea is that Tailwind's gameplay design should abide by Gee's good learning principles as much as possible, so that learners are willing and able to learn the game. Tailwind should also be designed in a way that incorporates as many situated examples of vector mathematics as possible, and it should involve puzzles that encourage the use of the problem-solving reasoning found in vector mathematics. It follows then, that when players learn how to play Tailwind, they are also implicitly learning how to use vectors in a situated, game-based manner. Finally, through the replay system and other peripheral features (which will be discussed in later sections), teachers can easily refer to the experiences and mental images that Tailwind created and formalize them in a way that is academically useful. Thus, facilitating the teaching of vector mathematics.

Given the three necessary conditions of a game being educationally valuable that we identified earlier, such an implementation should serve to practically, and effectively assist in the teaching of basic vector mathematics. A large portion of Tailwind's effectiveness as a teaching tool depends on how well the game's design abides by Gee's good learning principles and how well it shows examples of vector mathematics in action. If Tailwind is meant to create mental images that educators can refer to, then it is only as good as the mental images it creates. So then, for the scope of this paper, we will be focusing on evaluating Tailwind's incorporation of good learning principles, as well as its ability to generate and present examples while also collecting feedback so that we can come up with effective means and features to help teachers use Tailwind in their classrooms.

## TAILWIND: ALPHA VERSION DESCRIPTION & METHODOLOGY

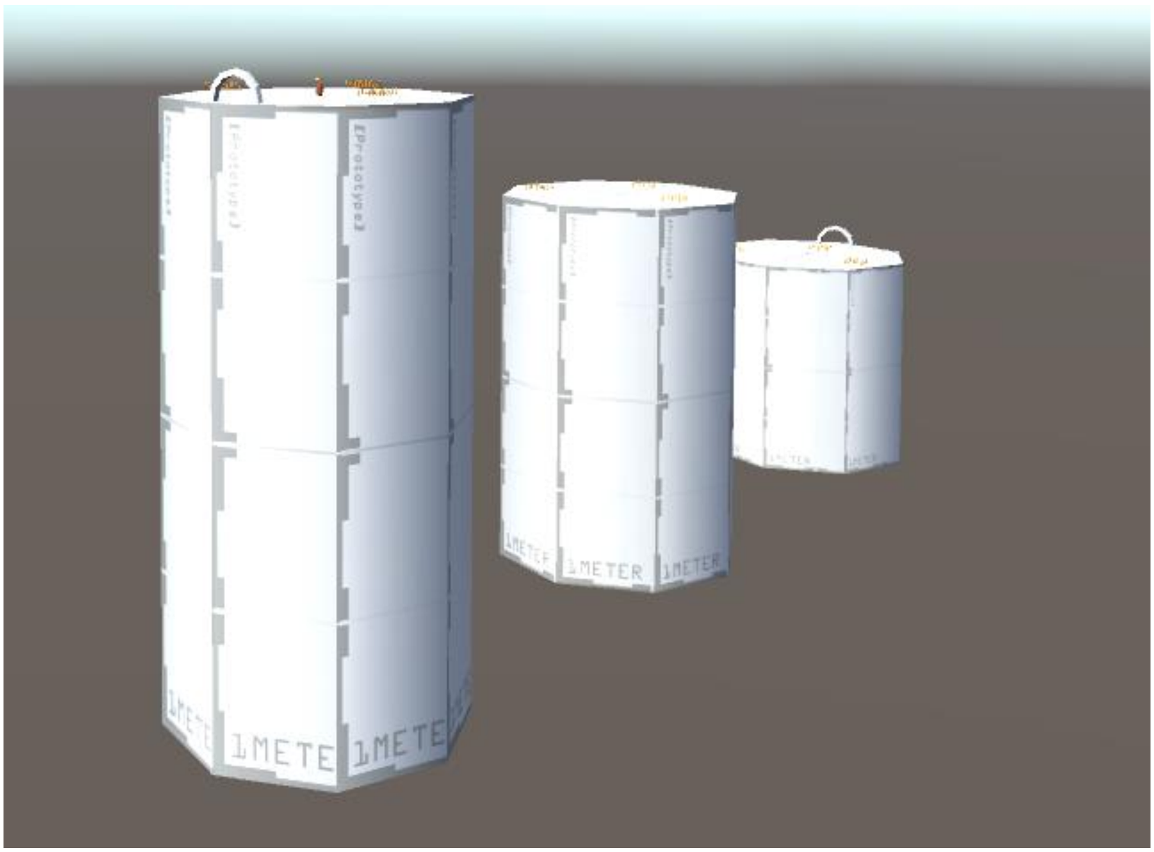


*Figure 3: The first level in the alpha build of Tailwind*

Tailwind is a 3D puzzle platformer, built with the Unity3D game engine, meant to help math and physics teachers cover the basics of vector mathematics. The player assumes control of a capsule character (affectionately dubbed as “Captain Capsule” by testers of the game) with the objective of traversing several different levels while collecting as many orb collectibles as possible. Players can run, jump and glide their way through the levels while interacting with the game’s wind system which can either help, or hinder their movement when gliding. Each level has a designated goal that the player can cross once they've collected enough of the orbs that are present in the level.

One of the main aspects of Tailwind is the wind system, which also constitutes the primary way learners are exposed to basic vector mathematics. The wind can blow in any of the eight cardinal directions, with varying intensity and affects the player's movement while gliding. Simply put, if the player glides in the same direction as the wind, the player will go faster. Likewise, if the player tries to glide into the wind, their velocity will be affected accordingly. More often than not, collectibles in the levels are placed such that the player has to glide to them with the appropriate directional input, thus creating a 'movement puzzle'.

The first iteration of Tailwind was very much a minimum viable product meant to test how fun, approachable, and attractive the proposed gameplay scheme was, and at this point in time, there were few certain things about Tailwind. The game had a goal of incorporating rudimentary 3D platformer mechanics like running, jumping and collecting, while also introducing an added level of complexity via gliding in accordance to some nebulous 'wind system' which had not been fully defined yet. The game lacked any clear aesthetic and many of the game's core features like movement and camera controls were still being developed. In order to encourage planning and to help players get a view of the different levels, this iteration featured a top-down camera mode that players could use to get a birds-eye view of the level they were in. The feature was later adapted into the game’s mini-map that is present in the final version, but was nonetheless present in the alpha testing.

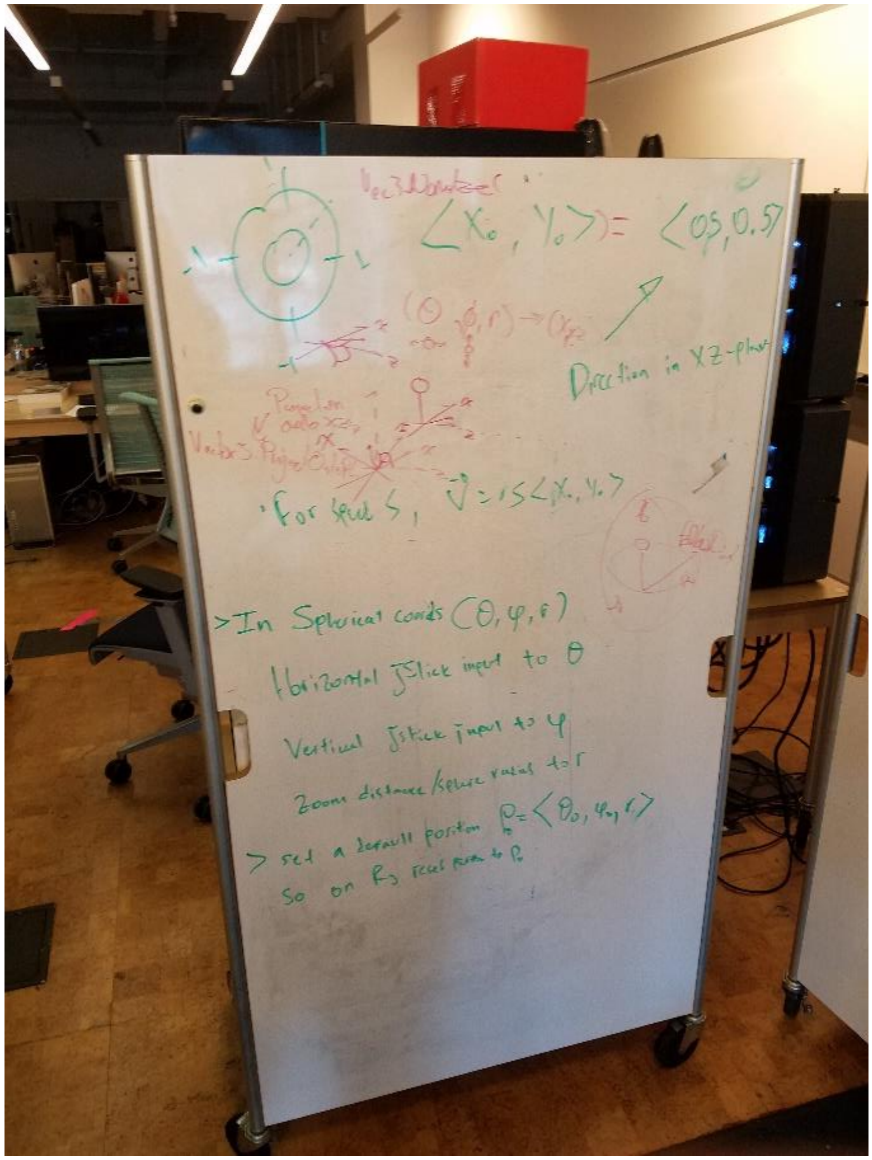


*Figure 4: Brainstorming Session for the Camera Controls*

At this point, the game’s wind system was also implemented in a very different way than what would end up in the later versions of the game. While it was still the case that the wind could blow in any of the eight cardinal directions, the players had complete control over what that direction was. The players could simply use a button on their controller to flip between wind directions until the wind was in their favor. The reasoning behind this implementation was that the players would almost be ‘solving’ for the right wind direction while trying to get to the next collectible. Since the game had no interface at this stage, the wind direction was represented by a big yellow arrow hovering above the player at all times, which would rotate to show the wind’s direction at any given moment. The game thus had a focus on moving from platform to platform, more so than actually collecting collectibles.

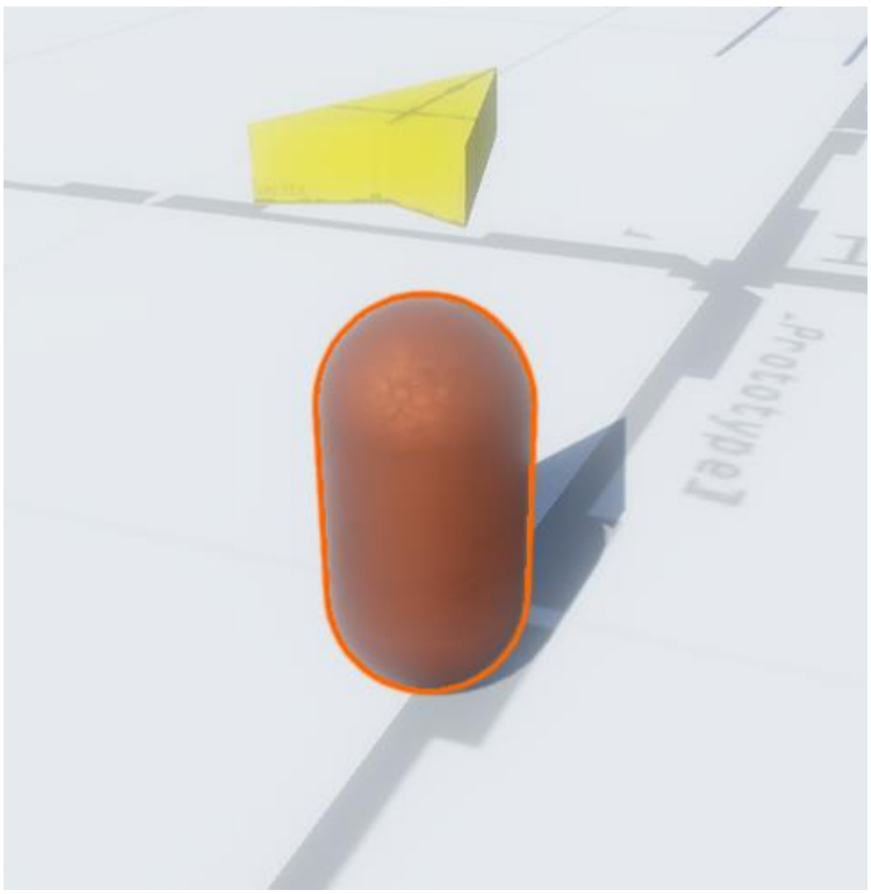

*Figure 5: The Alpha Wind Direction Arrow*

This version of the game was to be tested as soon as possible and featured three demo levels in order to get enough qualitative feedback that would be used to determine the game’s direction and mechanics. Testers of the game were split into three different groups and were encouraged to give different feedback depending on their academic status. The three groups were identified as **teachers, learners,** and **players**. Teachers were defined as individuals who had some experience teaching, either in a formal high-school setting, or in an after-school, extracurricular setting. Learners represented any student testers, currently in high school, and players were neither teachers nor learners. While teachers focused on giving feedback regarding possible uses of Tailwind in the classroom and learners gave feedback regarding the situation of academic material, players were still an important testing group as they focused on giving valuable gameplay related feedback more than the other two groups.

The testing session would follow simple play-testing rules in which players try out the game, one at a time, after a simple explanation of the controls, the premise, and the goal. The players were allowed to ask questions during gameplay, although not many of them did, and were also encouraged to point out anything that they found difficult to understand, or frustrating. If a tester was a teacher, they were also asked to consider the usability and applicability of a game like Tailwind in teaching environments that were similar to the ones they'd experienced. During the entire experience, I would also observe and take notes in an effort to identify any interesting occurrences that the testers failed to report, either with verbal feedback during their gameplay, or in their feedback sheet after they were done.

## TAILWIND: ALPHA VERSION RESULTS

The testing concluded with thirteen (13) testers, three of which were learners, four were teachers, and the rest were players. The session lasted for one week and testers gave a variety of feedback including gameplay issues they might have had, possible ideas for educator features, as well as any bugs they encountered. Luckily, the game was in a good enough state, such that there were no game-breaking bugs and every tester was able to make it through all three demo levels. People initially stated that the game was too difficult to complete but they were generally able to get used to the controls fairly quickly.

The biggest point of discussion for all testers was, without a doubt, the implementation of the wind system in the alpha version of the game. Even though there was a large yellow arrow on top of the player at all times, testers cited the lack of situated visuals as a big source of confusion when it came to how the wind worked. Even after an explanation of how the wind system functioned, many thought that they could only glide if they were facing in the direction denoted by the arrow. Others also reported that the visual itself was unclear and that it was hard to tell which way the arrow was pointing unless the camera was pointed in a certain way.

The implementation of the wind system also affected immersion, especially for the learners that played the game. Using the word ‘wind’ to describe the mechanic built some expectations of the visual cues the player should look for when interacting with the mechanic, which were simply absent. It felt to them that it was only called wind because of convention but it ended up functioning and looking more like a jetpack, or propulsion mechanism of sorts.

Testers also seemed to think that this implementation of the wind system could get very tedious and would also allow for several degenerate strategies. Because of the nature of the demo levels, it quickly became clear that the most efficient strategy to get through the levels was to point the wind direction directly at the next collectible and glide in that direction since the player's speed was highest when gliding in the direction of the wind. It is also worth noting that the direction of the wind was changeable in mid-air which resulted in players using the wind a steering mechanism, thus emphasizing the dexterity aspect of the mechanic more than the intended problem-solving aspect.

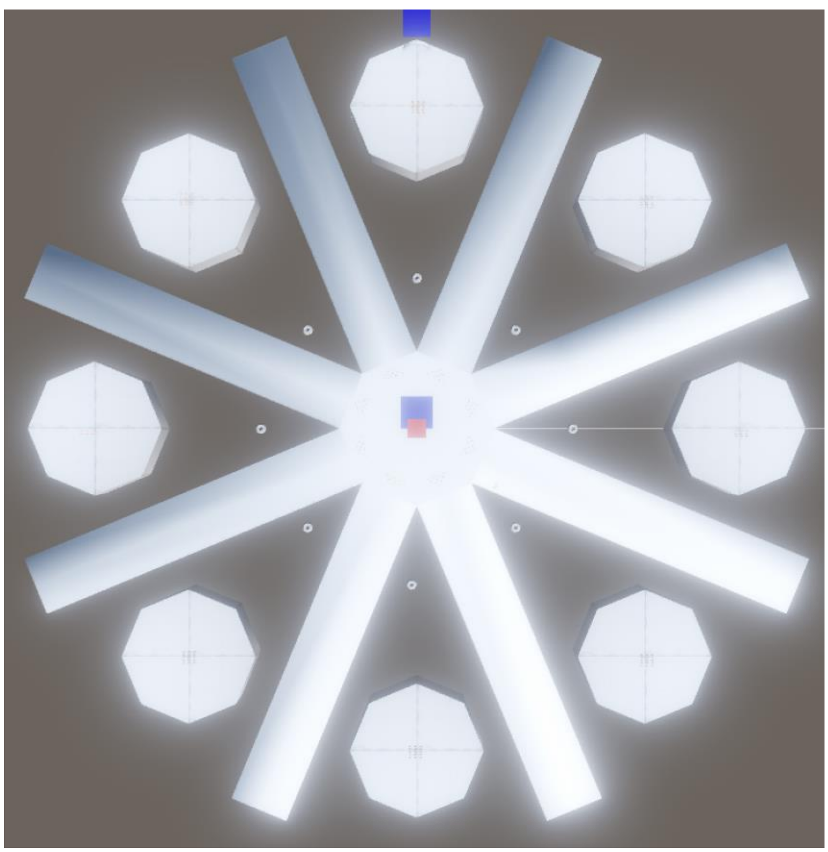

*Figure 6: The Alpha Top-Down View of the Third Alpha Level*

Another big point of contention would be the top-down view that was present in the game at the time. The intended purpose of such a mechanic was to give players a different point of view of the level so that they could situate themselves if they got lost or plan their route to the next group of collectibles. Unfortunately, testers did not see the purpose of having a bird’s eye view and felt like it disrupted gameplay too much, taking away from more fun things like jumping and gliding. A subset of testers offered feedback in an effort to improve the mechanic, saying that it felt odd that they couldn’t control this camera mode like they could the normal camera and that perhaps the mechanic would be more useful if they could rotate the camera around the level instead of just getting a top-down perspective. This mechanic was so underused and problematic however, that it would not make it past the alpha build of the game.

Other general gameplay issues cited generally concerned the tactile feel of the game when it came to the controls and physics of this version. In an effort to incorporate real-world physical calculations, the game functioned on a realistic measure of gravity acceleration of 9.81 $m/s^2$ which resulted in very floaty and unresponsive character movement, especially while gliding. This, coupled with an unintuitive control scheme for the gliding mechanic made the concept unattractive to a subset of the testers, especially those with less experience playing video games with a controller.

During this round of testing, the game was only playable using an XBOX360 (fig 4) controller and players could glide using the right bumper button (denoted RB in the layout below), this was very confusing to some and many would instead hit the right trigger (denoted RT) out of habit or would get confused and hit the left bumper (LB). This generally caused the most deaths for testers trying to get through some of the tougher sections of the demo levels.


*Figure 7: The Layout of the Xbox360 Controller Used for Testing*

Finally, when testers were asked about the aesthetic direction that the game should take, a common theme that came up was a general nature theme (given the name of the game), but several testers also mentioned that the prototype aesthetic somehow fit the academic subject of vectors, even going as far as to draw a parallel between the alpha version's textures and the graph paper used in classrooms. However, such an aesthetic concept would have to be taken further in some way, perhaps with a more elaborate color scheme or with narrative that situated the aesthetic. Testers also commented on the platforms being too big and imposing, saying that they took up way too much room that could be used for jumping and gliding instead.

When teachers were asked how they felt about the current iteration of the game and how they would use a game like this in their classroom, it was very clear that there were two emergent reactions to the concept of Tailwind. The first offered a more conventional opinion saying that the game could definitely use more representational aspects linking the game to vector mathematics, so that teachers can make sure that the game checks enough boxes to be used in a real classroom. Pointing out the large gap between learning how to play Tailwind and actually being able to go through a math problem set, they would like to see a game mode that would make the player input parameters to make the character move automatically to the next collectible. In essence, reversing the gameplay flow and helping the game highlight the academic aspects of doing vector mathematics.

The second group of teachers were generally optimistic about the concept and quickly jumped to discuss features that could help them use Tailwind in their classroom. The teachers generally showed a desire to actually *teach* through Tailwind, rather than to have the game teach their students via representational aspects or via tutorials that defined and described vectors. If Tailwind were to keep going in the same direction, the teachers noted that it would be a great means of application of the knowledge that students gain in the classroom and perhaps a good means of assessment depending on how complicated the puzzles can get.

A final thing that was expressed was the ability to spectate gameplay while the students were playing the game which would help make Tailwind less of a break activity and encourage active learning during gameplay – a concern that was frequently cited by the teachers at this stage. It is interesting to note that when the second group of teachers considered the case of vector representation in the game, they agreed that the game was definitely lacking and that vectors were preposterously absent. However, they emphasized that the incorporation of vectors into the game should **not** interfere with the gameplay and that students should not feel like they have to do vector math to play the game, rather vectors should be come naturally in some aspect of the gameplay.

Despite the limitations that would commonly be associated with such an informal user-testing process featuring a small sample-size, the feedback that was received at this stage was extremely valuable and helped shape the final version of Tailwind in multiple ways. It turns out that the assumptions behind the initial implementation of the wind system were severely lacking and were not conducive, neither to good gameplay nor to good learning. The control scheme and game feel were also not *quite* right and the feedback on possible teaching applications would provide valuable guidance when considering what extra features to add in order to make Tailwind usable in a modern classroom.

## TAILWIND: BETA VERSION DESCRIPTION & METHODOLOGY

The beta and final version of Tailwind for this project was heavily constructed with the feedback from the previous round of iteration in mind. Keeping in mind that Tailwind had to remain a good learning game, while evolving to be an asset for teachers to have in their classrooms, it was crucial that the feedback from the previous round of user testing was interpreted correctly. While the general premise of running, jumping, and gliding with the wind in order to gather collectibles still remained the same, there were numerous changes to many different aspects of the game.

Most notably, the wind system was completely revamped and with it, came numerous changes to the overall tactile feel of the game, along with a new direction in level design that was based on the new wind concept. Instead of the players being in control of the wind's direction, the wind in this version was an autonomous agent, able to change directions on the fly in order to present the players with different challenges as they traversed the new beta levels. This was done so that the game's control scheme can be lighter and less demanding, and also so that there was more of a puzzle-solving feel to the game. The idea was that since wouldn't have to worry about changing the direction of the wind anymore, they could focus on better controlling their movement and gliding and perhaps gameplay would flow more naturally.

To further understand what goes on during a play session of Tailwind, we will examine a typical screen that the player might see when playing, taken from one of the prototype builds of the game. In the next few images we will also get a glimpse of the game's new aesthetic that is definitely a play off of the graph paper comparison that was drawn in the feedback of the previous iteration.

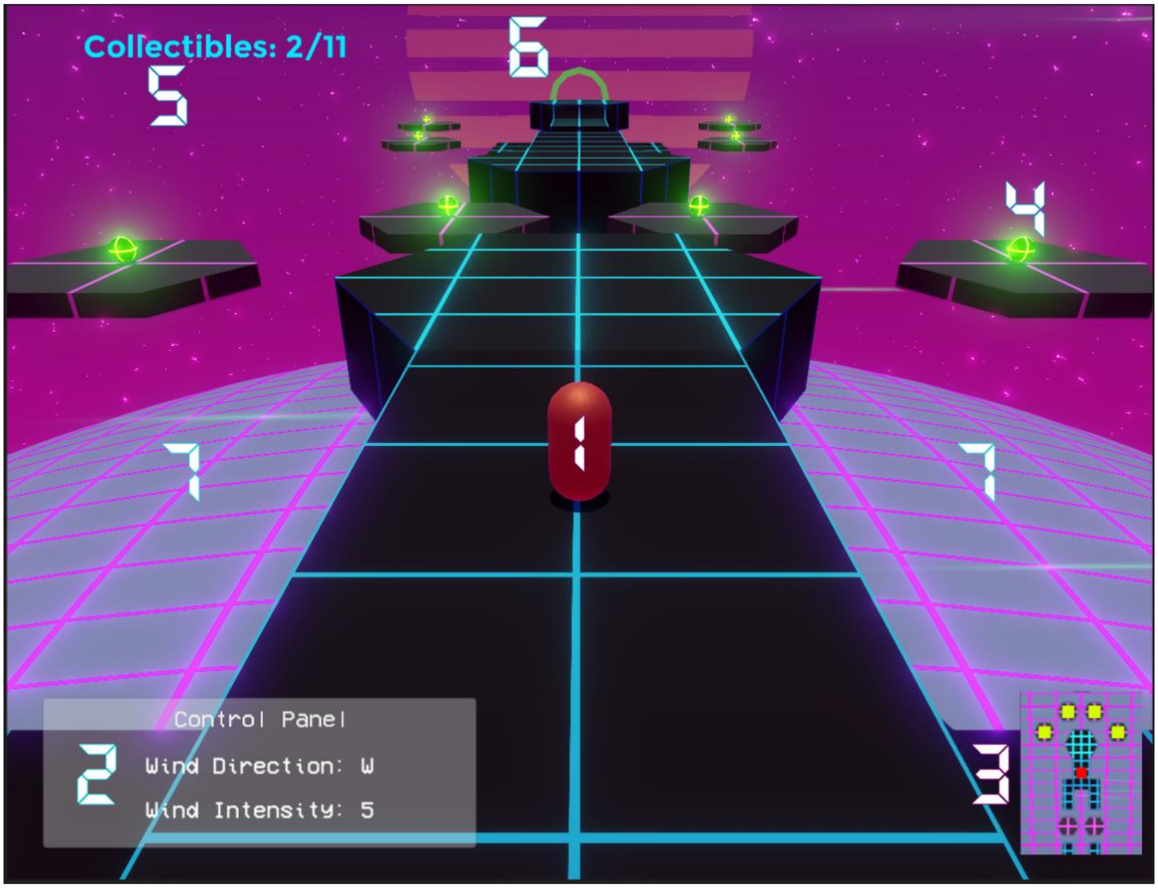


*Figure 8: A Typical View in the Tailwind Beta*

In the figure above then, we have the following according to the markers:

1. **The player**, Captain Capsule.
2. **The control panel** that relays numerical information about the wind to the player. Here the player can see the wind direction and wind intensity.
3. **The minimap**, in which the player can get a birds-eye view of their immediate surroundings. The player is represented with a red blip, while the collectibles are represented with yellow blips.

4. One of the **collectibles** the player must collect by making contact with it.

5. The player's **collectible counter**. Shows how many collectibles there are in the level, and how many the player has so far.

6. **The goal**, through which the player can advance to the next level. The goal is green when active, signifying that the player has enough collectibles to advance.

7. **The wind,** which is visualized as green wind wisps. The wisps will travel in a straight line along the direction indicated in the control panel. The wisps will also travel faster or slower depending on the wind intensity. The wind wisps along with the control panel were an attempt to increase vector representation in the game in response to the feedback received in the previous session of testing.

One of the more involved features in Tailwind that isn't found until a level is completed, is the **replay system** that can record a student's attempt at completing a level. Upon completing a level, the players get a chance to save their gameplay to a file so that they may submit it to their teacher via electronic means (email, submission to a google drive etc.), or save it for later viewing. It is also worth noting that, during normal gameplay, the players have an option to hit a "capture" button (assigned to the SELECT button in prototype builds of the game) that will automatically save the last 30 seconds of gameplay so that the player can submit a snippet of their gameplay instead of the entire level.

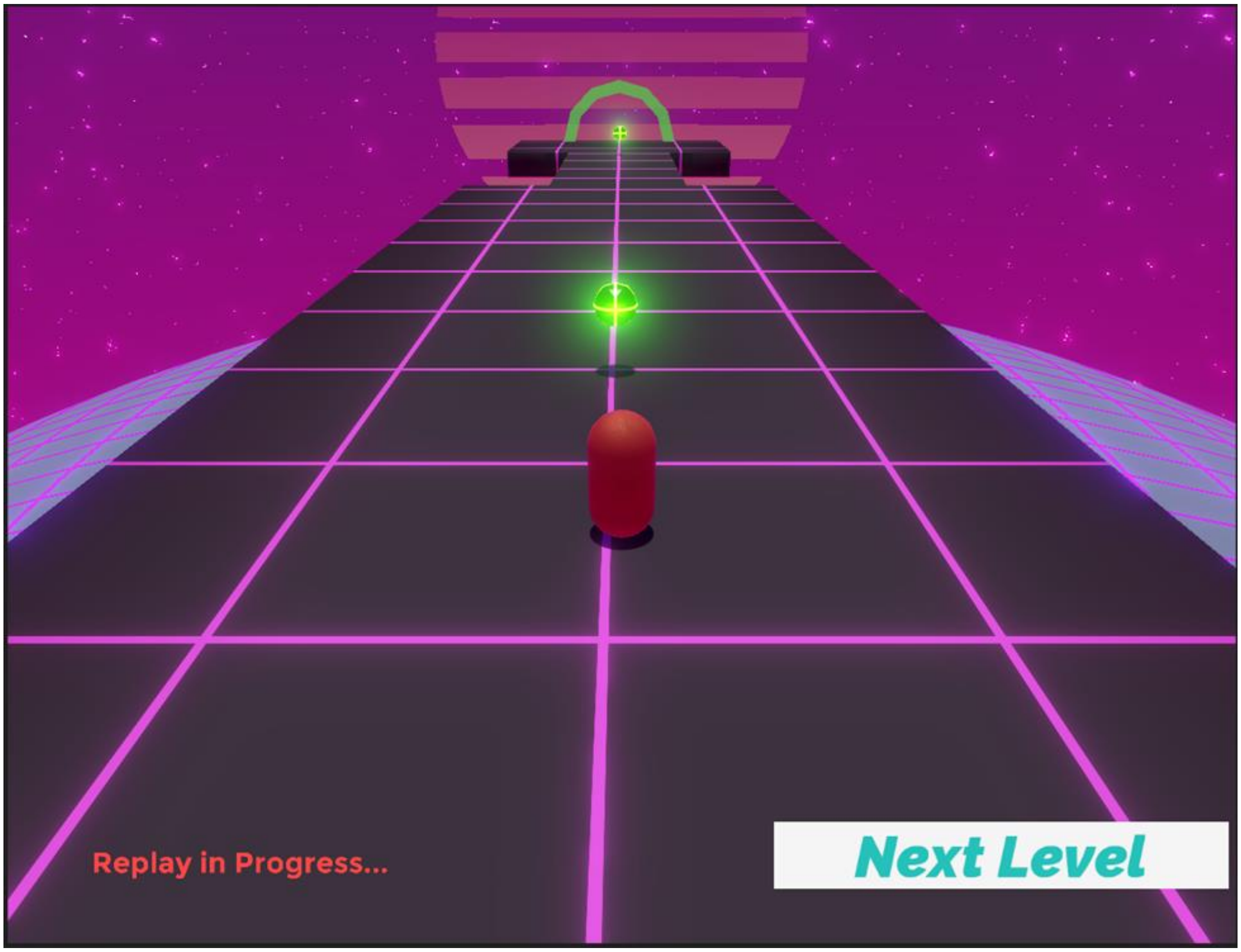


*Figure 9: The Beta Interface When Viewing a Replay*

The engine works by recording the position, rotation, and scale of each game object for each frame of gameplay. This data is kept in a list of frames in memory and recalled when needed, so that when it is played back, the system will essentially replicate players attempts at completing a level. It is very important to highlight that the replay data is very different from something like a video file format. Instead, the numerical data describing the position, rotation, and scale of each object can be stored in an .xml format and projected onto a dummy level, almost like a puppet show which allows for replays to be viewed on demand, without requiring a preceding session of gameplay. The structure of the replay data also currently allows for basic replay controls, such as pause/play and camera movement so that the replay can be viewed from a different perspective.


```xml
<Frame>
  <snapshots>
    <TransformSnapshot>
      <position>
        <x>13.3471766</x>
        <y>-8.167058</y>
        <z>36.5168343</z>
      </position>
      <rotation>
        <x>0</x>
        <y>0</y>
        <z>0</z>
        <w>1</w>
        <eulerAngles>
          <x>0</x>
          <y>0</y>
          <z>0</z>
        </eulerAngles>
      </rotation>
      <name>/TestPlayer</name>
      <isActive>true</isActive>
    </TransformSnapshot>
```


*Figure 10: A Snapshot of the Data Saved by the Replay Engine*

With these features in mind, this build of the game includes three levels that are to be used during testing. These levels have been built around Aki Järvinen's interpretation of game mechanics as verbs that constitute a player's vocabulary when interacting with the world around them. More specifically, Järvinen defines mechanics as a "means to guide the player into particular behavior by constraining the space of possible plans to attain goals", resulting in game mechanics that "are best described with verbs" (Järvinen, 2008). In the case of Tailwind, the player can:

1. **Move** on the ground and in the air
2. **Jump** short distances and heights
3. **Glide** in accordance to the wind

Expanding this thinking to the game's objectives, the player also must:

1. **Reach** the goal
2. **Collect** as many orb collectibles along the way
3. **Avoid losing** by not falling off the edge of the stage

Thus, we can look at the different levels in Tailwind as collections of puzzles that ultimately lead to the level's goal and require the use of different combinations of verbs to get through while avoiding falling off the edge of the stage. This will be done in order to ensure that Tailwind's problems are well-ordered, pleasantly frustrating, and generally do a good job of easing the player into the game.

We can also notice that all of the verbs the player has at their disposal are different manifestations of vector input. **Movement** is strictly a directional vector multiplied by the player's speed, **jumping** is an implementation of a force that is opposite to gravity, and **gliding** is an example of vector addition and subtraction, given that it lets the wind direction influence the player's movement. Therefore, when considering Tailwind's level design from a verb-analytic perspective, we can also keep in mind the underlying examples of vector mathematics that each puzzle offers.

In figure 10 we see a top-down view of the first level in the game, which is designed as a sandbox for testers to play in while the controls and premise was explained to them. Formally, this introductory level was conceived as an example of a puzzle that can be solved using only the **move** verb and was meant to introduce the general flow of the game. Playing off of Gee's idea of a sandbox, this introductory level is perfect for the player to jump around in, get familiar with the controls, starting point and ending point, the collectibles, and the general long and narrow design of the levels to come.

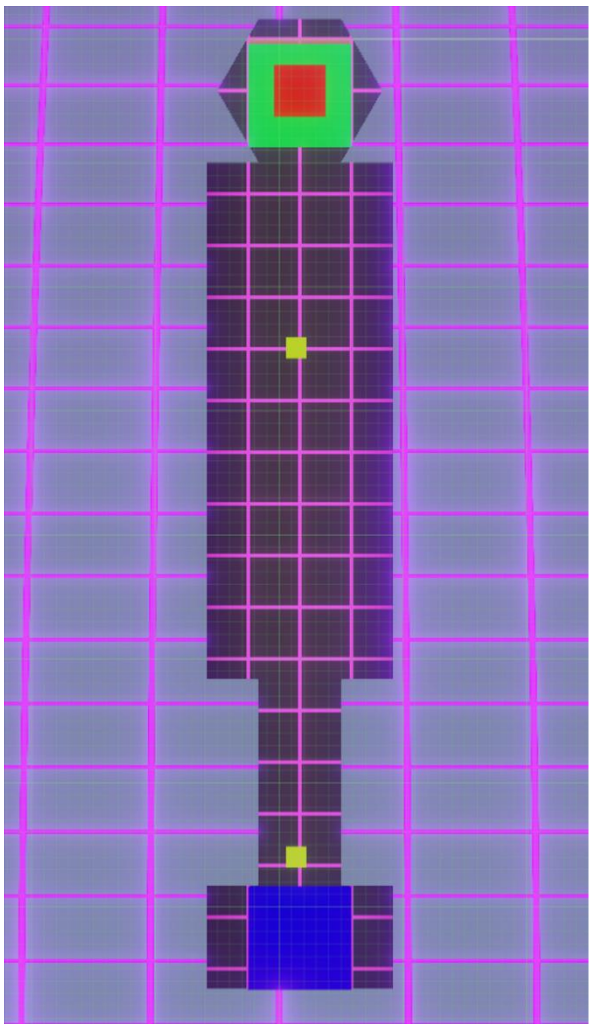

*Figure 11: Top-Down View of Beta Level 1. The red blip represents the player, yellow blips are collectibles, and green and blue blips are the beggining and end of the level respectively.*

In figure 11 we see a top-down view of the second level, which is designed to introduce jumping and gliding as mechanics to the player. The wind in this level randomly changes direction every twelve seconds and generally favors directions that point towards the goal that the player is trying to reach. The level is also split into three distinct groups of collectibles starting from the top where the green starting point is located and going down to the blue end point. The first group of collectibles present the player with their first set of jumps and have relatively short gaps that need to be closed, but generally do not require much input from the player. Simply hitting the jump button in any way will result in the player getting to these collectibles.

The second group, however, forces the player to make some more daring jumps, acknowledge the nuances of their movement, and generally play around with their camera more than they did earlier. While heading straight down the level, the players won’t notice the two side collectibles unless they either look at the minimap or stop and look around with their camera controls. Additionally, it’s highly unlikely that the player will make all the jumps without figuring out that movement controls are still available while they’re in the air, which is something crucial for effective gliding.

The third and final group of collectibles make it necessary that the player uses the gliding mechanics. The gaps between the platforms get increasingly larger and it becomes more and more important for the player to wait until the wind is blowing in the appropriate direction before they take off and attempt to glide to the next platform. Because of the wind’s semi-random direction picking, players should be incentivized to move while the wind is not entirely in their favor and thus experiment with different examples of vector addition while they try to glide efficiently to the next collectible.

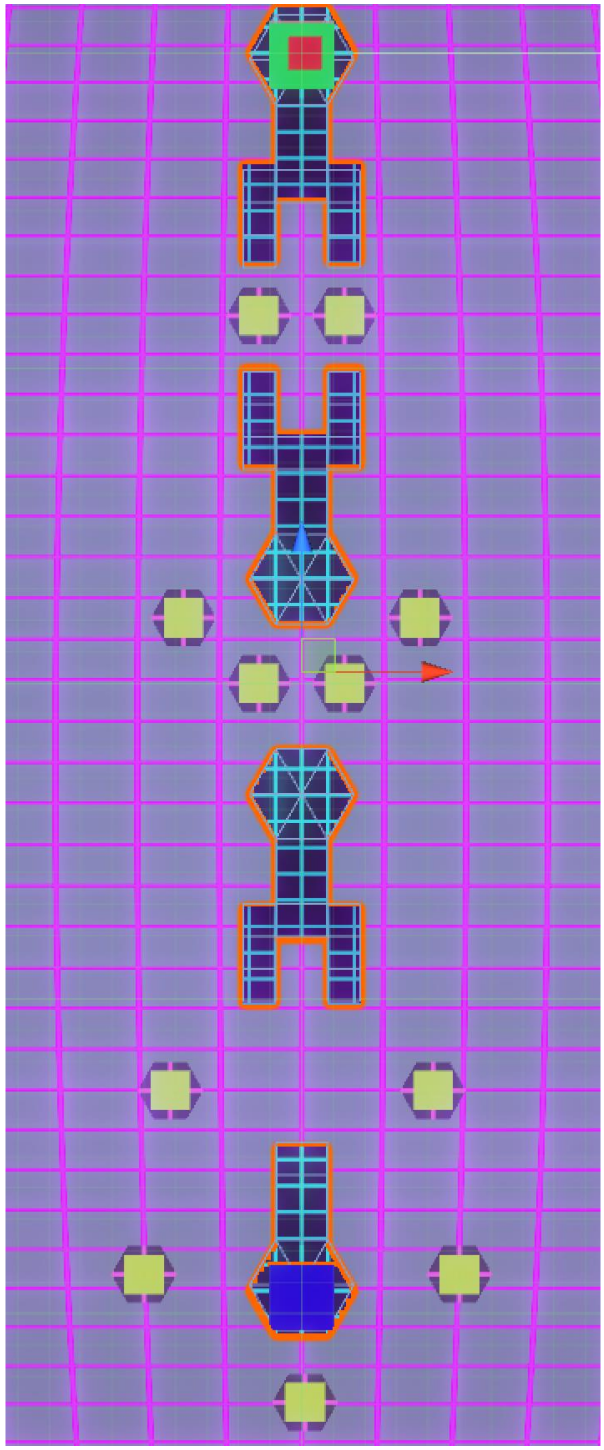

*Figure 12: Top-Down View of Beta Level 2*

In figure 12 we have a top-down view of the final level which was designed to experiment with moving platforms and introducing elevation as an aspect of the level design. Although in the top-down view the goal looks like it is placed behind the starting point, it is actually also several meters above the starting elevation of the player. The idea for this level is that the player will use the two sets of moving platforms to head towards the collectible on the southern edge of the level. The platform holding the southernmost collectible will also act as an elevator to raise the player high enough so that they can begin gliding towards the goal player, this long final glide was meant to be a victory lap of sorts for testers who got through all three levels successfully.

This is all made possible by the behavior of the wind that is unique to this level, which changes based on the position of the player in the level. In contrast to the previous level that features an intermittently changing wind direction, this level presents the player with a constant wind direction in an effort to place more of the puzzle solving onto the players having to determine the correct movement input in order to land where they want to. The steady wind direction in combination with the moving platforms are an attempt to simultaneously mix up and challenge what the players have learned in the previous level.

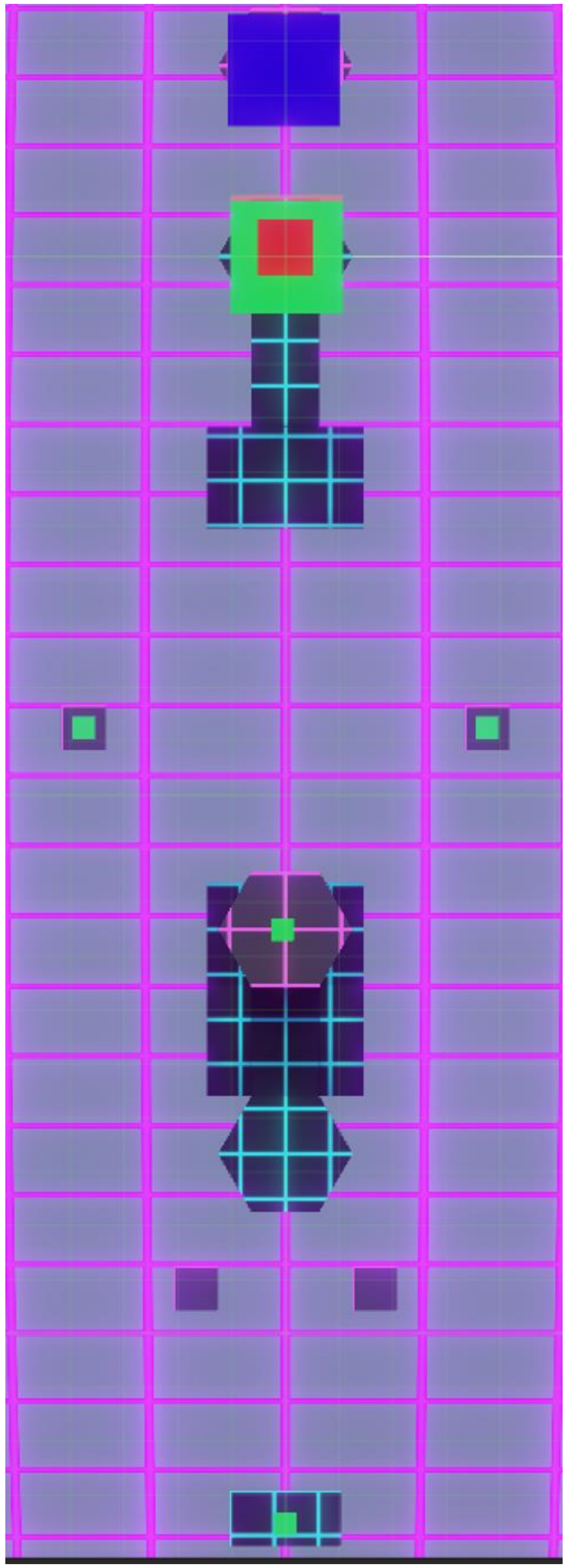

*Figure 13: Top-Down View of Beta Level 3. Here Collectibles are small green Blips to indicate that they are on moving platforms.*

Testers of this version of the game were given a pre-gameplay survey, as well as a post-gameplay survey in order to collect some data on the players, have a more structured approach, and generally draw some more concrete conclusions regarding the good learning characteristics of Tailwind. The pre-gameplay survey focused on personal information, like the player's age, their prior knowledge of vectors, and their habits of playing video games. Testers were asked to rate their knowledge of vector mathematics on a scale from 1 to 5, while also indicating how much of a 'math person' or a 'gamer' they thought they were. During gameplay, the player's death counter and collectible counter were tracked for levels 2 and 3 in an effort to get some idea of how well they performed in relation with their indicated math and game expertise. Before moving to the final stage of the post-gameplay survey, testers were also presented with a feedback sheet (similar to the one in the previous round of testing) and were encouraged to give as much feedback as possible.

The post-gameplay survey will presented testers with a summarized version of the RETAIN framework and they were asked to provide integer ratings for each of the different aspects of the framework. The definitions of the different aspects had been summarized in an effort to keep the survey relatively short while still getting the point across. We therefore knew in advance, that the resulting RETAIN score would not be a definitive score, given the fact that not all testers have teaching experience and that we could not control how well each of the testers understood the definitions[3]. Similar to the previous section, I was also

[3] Although it should be noted that they were encouraged to ask for a clarification if they did not understand something.

observing the testers during gameplay and recording any interesting occurrences. Because of a known bug in the controls of this version that might cause players to fall off the edge of the map, I was also making sure that the death counter was accurate by the end of the test. (For a complete version of the survey provided to the testers of this version please see Appendix C).

The results of this testing session would hopefully serve as a loose measure of Tailwind's effectiveness as a learning device which, ideally, was going to be at least acceptable while still maintaining a focus on good gameplay rather than on presentation of academic content. In addition to the survey results, testers that indicated having had teaching experience would also be presented with a demo of the replay functionality and would take part in a short discussion about possible extra features they would like to see and possible applications of a game like Tailwind in their own classrooms. The feedback from the interviews will be an integral part of the possible future directions that will be discussed in later sections.

## TAILWIND BETA VERSION RESULTS

The testing session concluded with 18 subjects, 5 of which indicated they had teaching experience and thus participated in the discussion regarding the replay system and potential extra features. When it came to quantitative data we had to consider a subset of 14 testers because of invalid data entry during the survey taking process. In order to highlight some of the trends that came up during gameplay, we categorized the testers based on the ratings of vector, math, and game expertise they indicated for themselves (on a scale from 1 to 5, with 1 being the least comfortable and 5 being the most comfortable). We then compared those ratings with the average collectibles gathered throughout the game, deaths throughout the game, as well as the deaths per collectible of each category. For conciseness, we will be referring to the measures of expertise as vector, math, and game score respectively.

First, we have the comparison between math score and the game's performance metrics (figures 13-15). While the total number of collectibles does not seem to have any noticeable relationship with math score, we can definitely see that there is a semblance of an inverse relationship between math score and the total number of deaths.

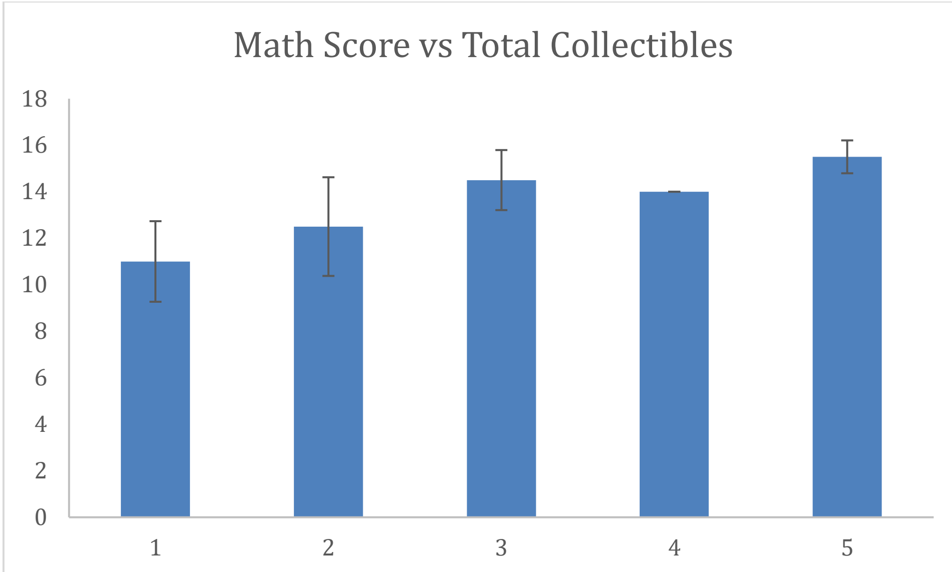


*Figure 14: X-Axis is Math Score, Y-Axis is Total Collectibles*

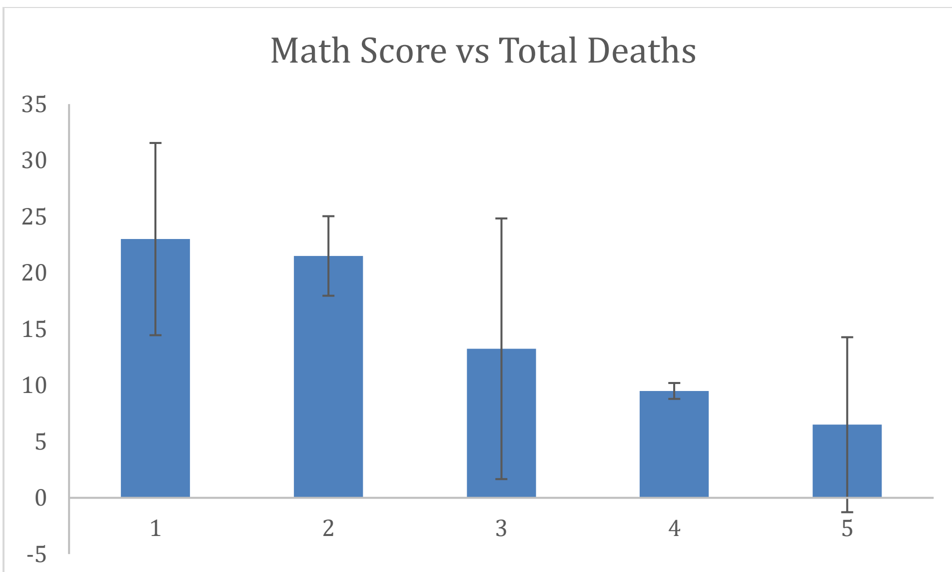


*Figure 15: X-Axis is Math Score, Y-Axis is Total Deaths*

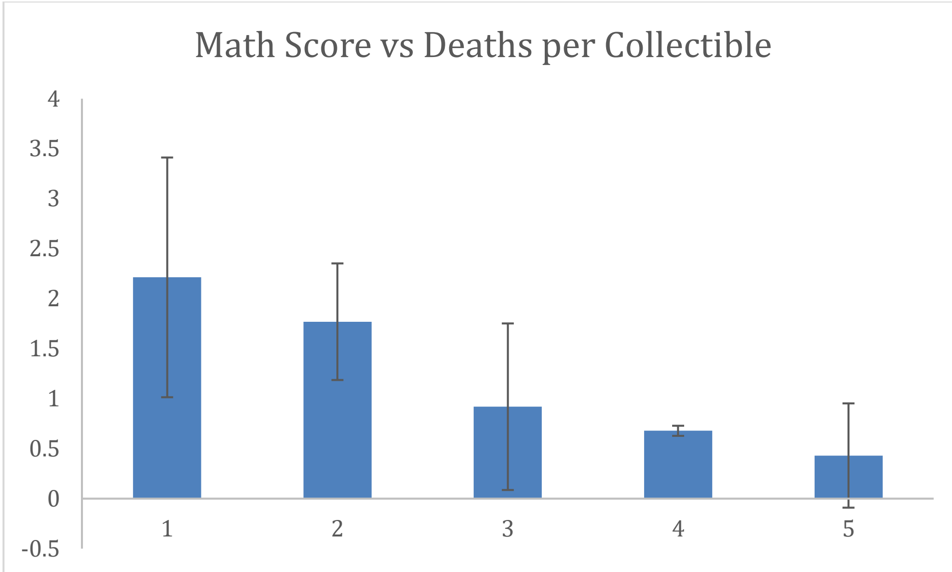


*Figure 16: X-Axis is Math Score, Y-Axis is  Deaths per Collectible*

By extension, players who reported higher math expertise tended to die less when attempting to get each collectible. As an extension to the reasoning above, we see the comparison between vector score and the game's performance metrics which tends to show the same information, although the drop-off in death count metrics is much sharper than with general math expertise (figures 16-18). This might serve to indicate that understanding about vectors increases the chance of success that players have when attempting to get collectibles, more so than just a general aptitude in math.

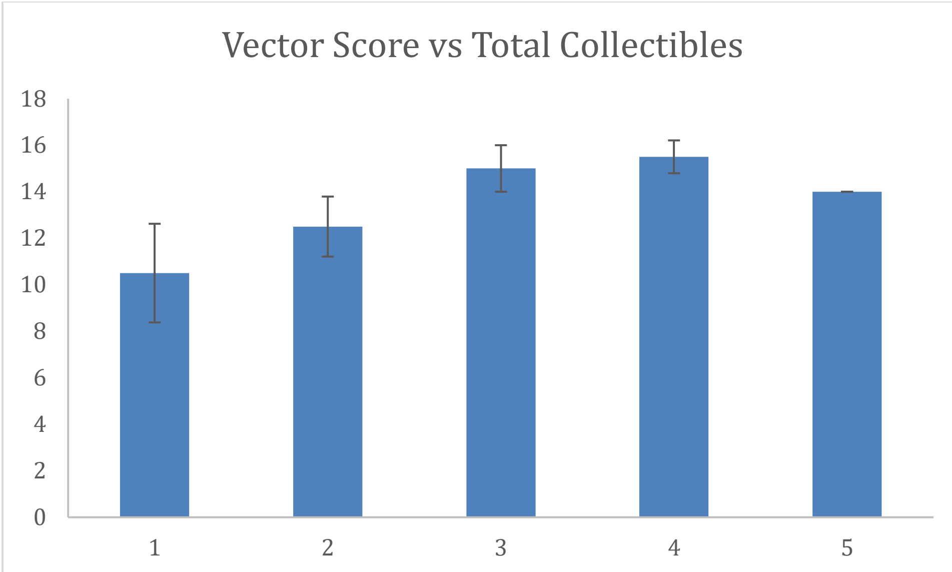


*Figure 17: X-Axis is Vector Score, Y-Axis is Total Collectibles*

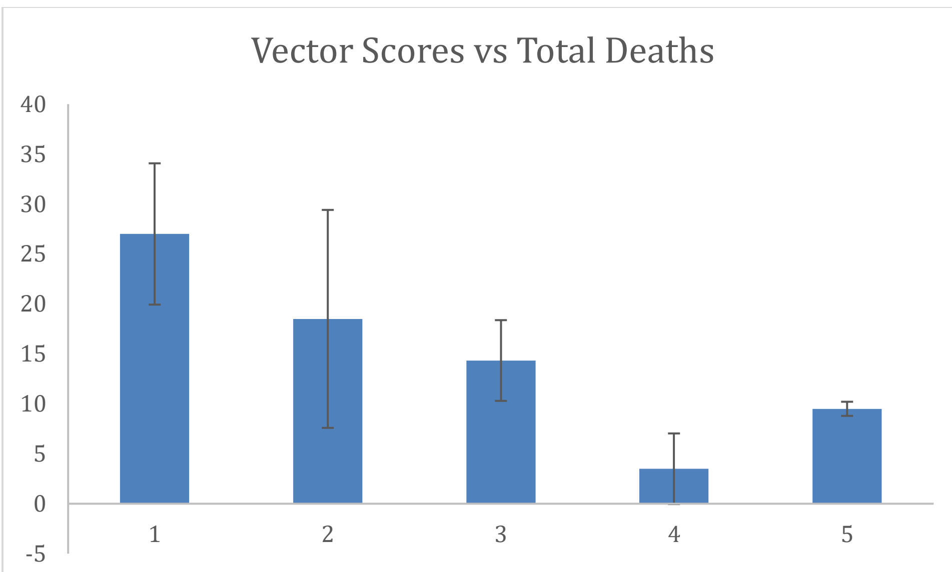


*Figure 18: X-Axis is Vector Score, Y-Axis is Total Deaths*

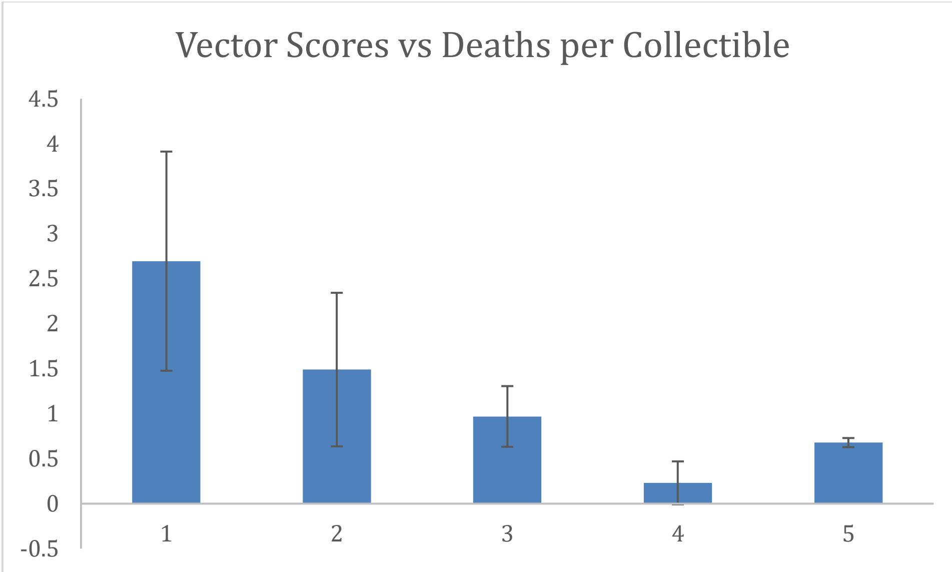


*Figure 19: X-Axis is Vector Score, Y-Axis is Deaths per Collectibles*

Finally, in an effort to make sure that the game is focused on education, rather than gameplay skill and dexterity, we will be looking at the comparison between game score and the game's performance metrics (figures 19-21). Given the sharp increase of total collectibles in relation to game score we can see that the barrier to entry for Tailwind seems to be low enough that a variety of players can pick it up and learn it fairly quickly, which is consistent with the behavior of testers in the last version of Tailwind.  While there still exists a drop-off in the relationship between game score and total player deaths we can see that it is far less consistent than the one in the previous categories, perhaps indicating that dexterity and general skill in video games is less important than the player's understanding of mathematics and vectors.

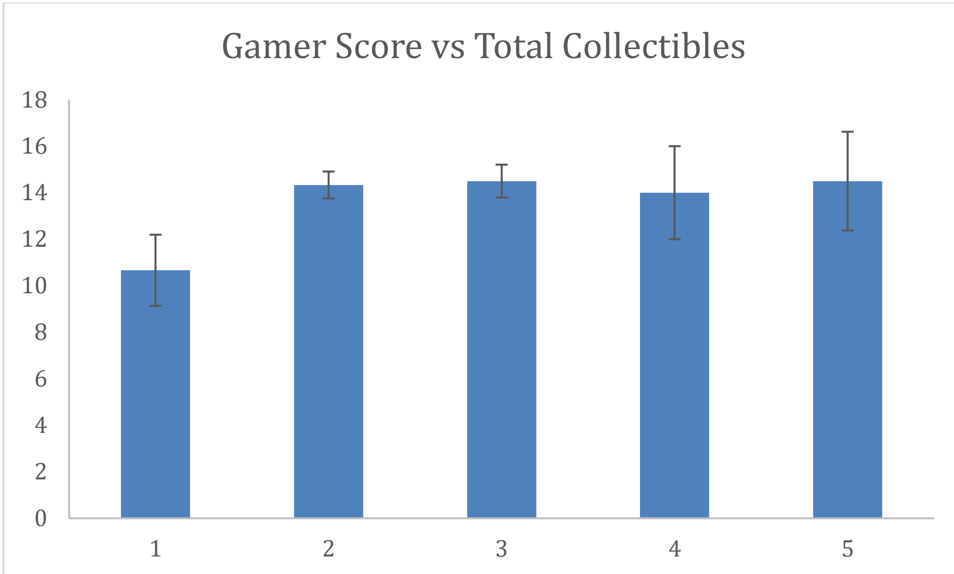


*Figure 20: X-Axis is Gamer Score, Y-Axis is Total Collectibles*

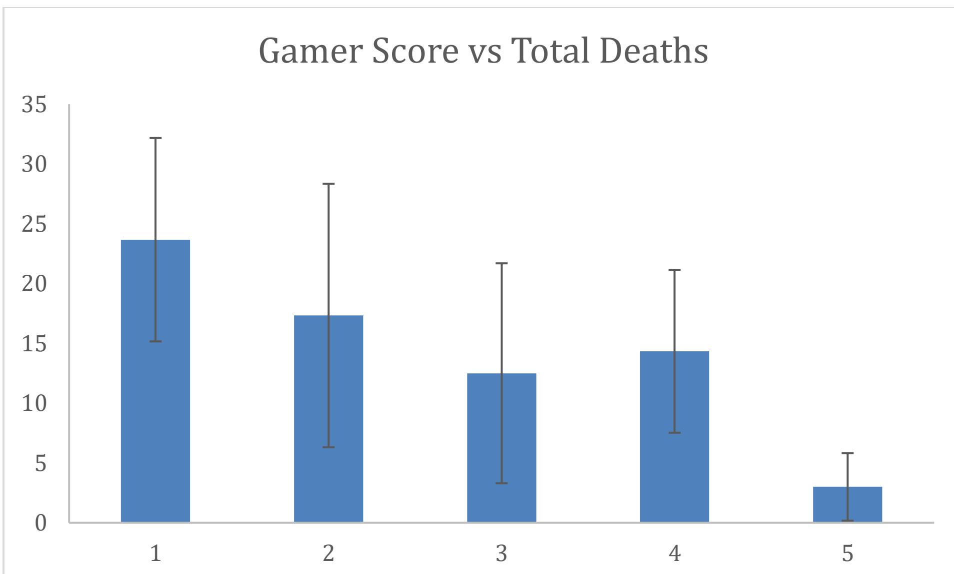


*Figure 21: X-Axis is Gamer Score, Y-Axis is Total Deaths*

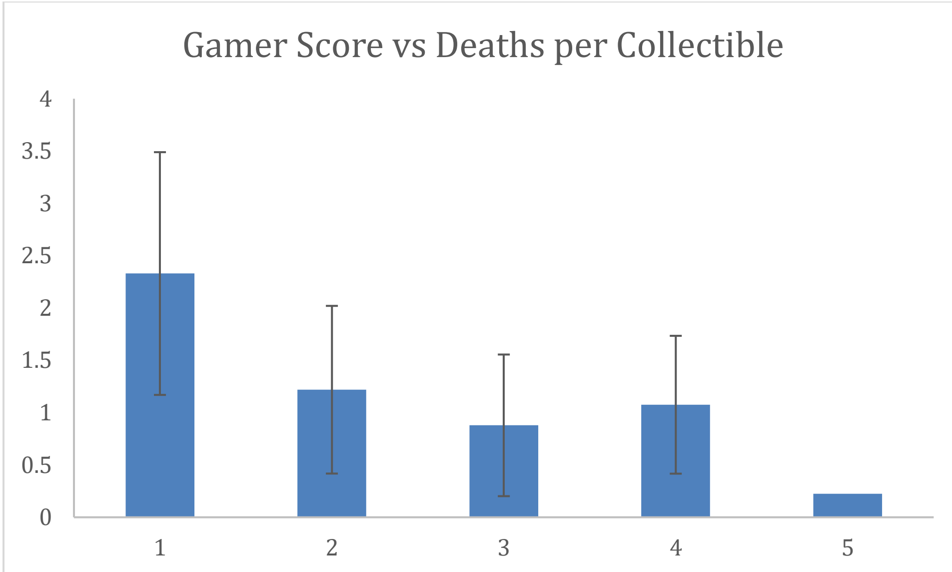


*Figure 22: X-Axis is Gamer Score, Y-Axis is Deaths per Collectible*

It should be noted that the number of subjects is relatively low for the purposes of drawing definitive conclusions from the quantitative data collected by the survey because most play-sessions ended up lasting longer than expected. Players generally made an effort to get all of the collectibles and since they had unlimited tries, they ended up spending a lot of time with the game. As such, these observed trends are **most definitely not meant to be predictors of any kind,** instead, they are meant to be relative checking mechanisms in terms of the game's character, direction and demands towards the player. The fact that players seemed reluctant to label themselves as "gamers" or "math people" may also play a role in the data we see and it should be noted that it was very apparent that some people were being modest when taking the survey.

The benefit of prolonged player interaction, however, was that players seemed thoroughly engaged and much more willing to provide qualitative feedback regarding the game. The extra time spent with the game, may have also served to make their given RETAIN scores more plausible and meaningful than was initially expected. In an effort to account for the testers being generous with their rating, the game's score on each category was averaged and *rounded down* to the nearest integer rating. This ended up giving the game a rating of 2 in every category except immersion and naturalization which received a 1. This resulted in a total score of 34 out of a possible 63, meaning that the game is at least acceptable when it comes to its RETAIN assessment. Below is a breakdown of the game's RETAIN score for each category, including the weights that are assigned to each category.

| | **Average Score** | **Weight** | **Resulting Points** |
|---|---|---|---|
| *Relevance* | 2 | 1 | 2 |
| *Embedding* | 2 | 3 | 6 |
| *Transfer* | 2 | 5 | 10 |
| *Adaption* | 2 | 4 | 8 |
| *Immersion* | 1 | 2 | 2 |
| *Naturalization* | 1 | 6 | 6 |
| ***Total*** | **10** | **N/A** | **34** |

*Table 3: Average RETAIN Scores for Tailwind, Including Weights and a Total Score. Averaged from Survey Responses*

For reference, a game like *Math Blaster!* has previously received an 18 on the RETAIN scale, while *Where in the World is Carmen Sandiego* received a score of 41 by the creators of the framework (Gunter et al., 2008). Given their analysis of the scores, suggesting that *Math Blaster* is inherently a worse educational game than *Carmen Sandiego* would be incorrect, given the character of the framework. Instead, the RETAIN score of *Math blaster* highlights the fact that it is weaker in areas that are thought to be more valuable with regards to the weights attached to the categories. The report summarizes it nicely in that *Math Blaster's* score is seemingly so low because it is “so focused towards improving very specific and focused set of skills” (Gunter et al., 2008).

Luckliy, Tailwind does not appear to be lacking in any specific category but instead fairs decently on every category. The lower scores on immersion and naturalization were expected because of the prototype nature of the game. The levels are completely finite and very much meant to be examples of what *could* be, thus providing little opportunity for naturalization given that the game is not replayable and does not expand on a variety of vector examples. Also, the lack of any player character or even any opportunity for the player to immerse themselves in some form of narrative would definitely explain the score received on immersion. In future iterations Tailwind should definitely expand to incorporate some kind of narrative or at least provide some opportunity for the players to immerse themselves.

On the other hand, however, we can look at the higher scores Tailwind received and see that the prototype of Tailwind is fairly successful in what it set out to be. The categories of relevance and embedding seem to highlight that the existing examples of vector math are well crafted and make it apparent that the game is meant to provide students with the opportunity to interact with vectors and to experience vectors in a unique way. The higher scores in transfer and adaption definitely highlight the good gameplay and learning principles that the game incorporates and validate the well-ordered and pleasantly frustrating nature of the game (especially since it resulted in players taking the time to thoroughly complete the game during testing).

In terms of qualitative gameplay feedback that the testers provided, there were two main points that consistently arose in the reviews that they left. The first had to do with the intermittently changing wind mechanic in the second demo level, which seemed to disrupt gameplay way too much, forcing players to wait for the right wind direction, and generally being the only noteworthy point of frustration with this version of the game. The second point that consistently came up was the lack of use that the players found for the minimap that was provided. Given the open nature of the levels and the general lack of visual obstructions, players did not find themselves using the minimap very often and stated that they would prefer the open camera space or a functioning compass more than the traditional minimap implementation.

In general, testers were much happier with this beta version of the game and were very accepting of the features and premise. While there were definite shortcomings in the sense that the number of testing participants was lower than what had been expected, getting to see every participant take the time to interact with the game and show definite signs of enjoyment was very promising and reassuring for any future iterations.

## TAILWIND: NEXT STEPS AND FUTURE CONSIDERATIONS

The original dual purpose of Tailwind was on one hand, to prove itself as an effective learning title purely via good game principles, and on the other hand, to make the first steps in understanding the identity of a teacher friendly game. The testing conducted for this project has definitely addressed the former of the two concerns and we therefore have a solid foundation to begin considering Tailwind's move into a real classroom environment. Using the four-dimensional framework, we can highlight some of the goals that the next prototype version of Tailwind seeks to accomplish in a more structured way.

| Context | Learner Specifications | Pedagogic Considerations | Mode of Representation |
|---|---|---|---|
| A combination of gameplay at home and discussion of gameplay during pre-calculus or AP Physics class | US School learners aged 15-18 | Experiential learning during gameplay, followed by reflection and formalization in the classroom | Tailwind will move away from using using a low level of fidelity in terms of interface and animation. |
| Interactions with the game at home and interactions with replays and screenshots in class | Tailwind *should* cater to a variety of learning styles because of the variety of content type (mechanical, visual, kinesthetic etc).<br>This also depends on the class reflection however. | Learning outcomes: familiarity with vector notation, velocity vectors (magnitude, direction, and scalar multiplication), vector addition, and vector subtraction | Incorporation of a narrative and story element. |
| Tailwind is meant to supplement the common core teaching standards | The tool can be used by groups of learners but is intended to be used by students as a homework activity | Learning activities: Gameplay, submission of replays, identification of vector concepts in puzzles, written reflections, paired gameplay sharing through replays | |

*Table 4: Four Dimensional Analysis for Tailwind's Next Steps*

Tailwind's next iteration will be designed with several different scenarios in mind, all of which involve introducing Tailwind into a US AP Physics or pre-calculus classroom. After an initial introduction to the topic, along with their normal homework, students will be instructed to play through the introductory levels of Tailwind and submit at least one replay to the instructor through electronic means. The instructor would then sift through the material, as if grading homework, before the next class in order to compile footage to use as examples during class discussion. Perhaps encouraging participation during reflection to verify the understanding of the material, or by conducting a walkthrough of a particularly interesting replay that may have been submitted.

As a means of situating Tailwind in a classroom environment like the one above, we would need to consider and implement several educator features that are based off of feedback provided by testers who had educator experience in the testing of the beta version, and also different educators who provided feedback during the creation of Tailwind.

The ability for a teacher to view replays easily and quickly definitely came up during discussions and the idea of a **standalone replay client** could definitely accommodate this request. When viewing a replay, none of the physics calculations that power the game are actually performed, and instead, objects are simply moved to the correct position each frame. It is then not hard to imagine an independent version of Tailwind (that is, a separate computer program or even mobile application) that would only contain still, empty versions of the levels of the regular game. This version would have none of the physics, scripting, or gameplay features from the regular version of Tailwind, but would instead serve simply as a platform to view replays on without needing access to a computer powerful enough to run the full game.

Building off of this, the nature of the replay data would also allow for the viewer of the replay to have a complete set of controls that would allow for manipulation of the camera, pausing/playing, toggling vector visuals, and capturing screenshots so that Tailwind can be used to view gameplay from a different perspective and generate material for use in the classroom. An extension of the control scheme provided during replay viewing would be a set of annotation tools that are available to the teacher. Tailwind could perhaps provide educators with access to a set of simple drawing tools, including a pen, line-drawing tool and an eraser. This will allow the teacher to pause the replay and essentially draw over a still frame of Tailwind so that Tailwind can effectively be used in a classroom environment.

To encourage Tailwind's development as an effective educational device, the game will also need to incorporate a set of in-game vector visualizations that more closely represent the vector notation that students come across in their regular studies. In order to maintain a focus on good gameplay rather than representation, this must be done under the assumption that they are not integral to the gameplay and can be toggled on and off. In theory, simply being able to display velocity vectors of moving objects in the game would not detract from the gameplay experience and would perhaps serve to empower teachers even more during their teaching with Tailwind.

Finally, we must consider the general takeaways that the educational testing of Tailwind has provided us with. It is very much likely that Tailwind has succeeded solely on the basis of good gameplay because its subject matter, which is vector mathematics, lends itself well to the genre of 3D platforming. The replay and peripheral features could also go through the same scrutiny in the sense that observation through replay and annotation seems to fit very well with the concept of vector mathematics.

What would games that seek to cover other subject matter look like? Would their features be the same? It is easy enough to imagine more vector concepts or other geometrical and physical subjects being added to Tailwind, but what would games that want to handle more abstract concepts like statistics and probability look like if they followed Tailwind's footsteps? Expanding onto other concepts is also one of the future steps for Tailwind and ideally, the research done in this paper would be of use in future endeavors.

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