# Science at Play

***Research and Design for the* Martha Madison *Game-based Curriculum:***
*2017 Edition*


*Research White Paper*

second avenue

**kids**

+

**25-minute**
play session

+

**2-week delay**
between pre/post-test

+

**Ø**
teacher-led instruction

=

**kids**
excited
about STEM!

**10% increase**
in key content
learning

# Science at Play

***Research and Design for the* Martha Madison *Game-based Curriculum: 2017 Edition***

*Research White Paper*

## Low ranks

**32%**

of 8th grade students in the U.S. proficient in science

**35%**

of 8th grade students in the U.S. proficient in mathematics

**2.7%**

of minority students go on to earn STEM degrees









## Teachers want evidence. Students want to learn (and have fun). ***Martha Madison*** delivers both.

## Created with teachers and students. Aligned with standards. Proven to effectively improve student outcomes. From the very beginning, the ***Martha Madison*** game-based curriculum has had research at its core.

A few years ago, a team of educators, game designers, and software developers asked this question: Would it be possible to introduce science through an entertainment-quality videogame, in a way that would improve interest and learning in science, technology, engineering, and mathematics (STEM)?

This cross-disciplinary team at Second Avenue Learning was already dedicated to the creation of robust, innovative solutions that transform the educational landscape. Recognizing a growing crisis in STEM education, the team had turned their attention to STEM education for students who are at one of the most critical stages in human development and learning: the middle school years.

The National Science Foundation was interested in this topic as well. Recent results on national and international tests have indicated that U.S. middle school students perform relatively poorly in both science and mathematics, especially compared to their counterparts in other developed nations. Moreover, female and minority students lag significantly behind their peers in STEM, leading to a marked under-representation of these groups in the STEM workforce.

In 2011, the NSF awarded Second Avenue Learning with a Phase I grant to develop a prototype for a physical science game for middle school students and their teachers. Designed to address students' lagging interest and performance in STEM, the game utilized a problem-based learning approach, with each game mechanic aligning with specific learning objectives and Next Generation Science Standards.

**It takes focus**

# 95%

**of student communication during gameplay was focused on science and collaboration**

Since that time, Second Avenue Learning has been awarded with additional grants (Phases II and IIB) from the NSF to develop a full game-based curriculum suite for middle school physical science. Here, we describe the extensive qualitative and quantitative research that has informed every stage of the design and development of *Martha Madison*. Our findings have demonstrated that *Martha Madison* is an effective and exciting approach to science education for students of both genders and across all socioeconomic groups. This research is key to the creation of products that not only enhance learning, but inspire young minds through fun, play, and exploration of authentic science.


» *Example of in-game scaffolding for* **Martha Madison: Optics**

**"This didn't feel like school. It is perfect!"**

8th-grade playtester

## Overview of the *Martha Madison* project

During the Phase I development of *Martha Madison*, Second Avenue Learning partnered with researchers and faculty from the Rochester Institute of Technology to study the effects of the game on students' collaboration, engagement, perceptions of STEM, and content learning. The first prototype game, titled *Martha Madison's Marvelous Machines*, was built with input from students, teachers, and subject matter experts.

Results and feedback from testing throughout the prototype development process were used to refine *Marvelous Machines*. Upon award of a Phase II grant from the NSF to continue development of the game, three additional games in the suite were developed: *Simple Machines* (gold master, based on the prototype), *Waves*, *Optics*, and *Forces*. Additional games in the curriculum are currently under development.

Students are introduced to key science concepts through an engaging narrative, which is presented by Martha Madison, the scientist meerkat who serves as a mentor and guide throughout the game. Working in pairs,

students select their animal avatars and then use the unique abilities of their avatars to help Martha Madison solve authentic science problems. All in-game challenges are directly tied to specific learning objectives and standards. A sandbox-style maker space allows students to create their own game levels and challenges, encouraging open-ended play and creation while providing teachers with revolutionary assessment options.

**"I liked the game because you got to choose different characters that help each other. I also liked how there were a lot of different levels that included several different skills. If this were my homework, I wouldn't have to complain about homework anymore."**

8th-grade playtester


» **Martha Madison data dashboard screens**

The *Martha Madison* suite has evolved from a successful prototype into a game-based curriculum, with all design influenced by research and feedback from students and teachers. The current curriculum includes the digital games, a robust data dashboard with multiple interfaces, in-game and paper-based assessments, as well as a full instructional resources package.

A primary vision of the *Martha Madison* project has been to create a rigorous, accurate, and effective intervention that will improve STEM performance, feelings of self-efficacy in STEM, and increased student affiliation with science and mathematics. To achieve this vision, Second Avenue Learning has engaged in multiple forms of research, ranging from informal benchmarking and playtesting to randomized control studies in school settings. Data collected from this research has informed the development of subsequent game and curriculum iterations, while also ensuring that *Martha Madison* effectively improves student outcomes.

### Preliminary Literature Review and Benchmarking

How does one formulate an idea for a serious game? At Second Avenue, we engage in research at every stage, including during the initial concept design. In fact, the initial principles behind the *Martha Madison* games were established as a result of an extensive review of existing theories and research in the areas of game-based learning, gender patterns in learning and gaming, and STEM instruction.

> **"I liked the feedback and advice the meerkat [Martha Madison] gave you. I wish I could keep playing"**
>
> 8th-grade playtester

Second Avenue conducted multiple benchmarking studies as well. During these studies, Second Avenue collected data on current entertainment games, as well as educational games and simulations for physical science, with a focus on offerings for the middle school target audience. This data provided Second Avenue with information about the strengths and weaknesses of products currently on the market, as well as critical gap areas.

Focus groups were held with middle school physical science teachers in order to establish a core set of unit topics, which were correlated to existing physical science curricula as well as the Next Generation Science Standards, Common Core Standards, and 21st Century Skills Standards. A second set of focus groups was held in order to identify "pain points" within each unit; that is, the key concepts that students found to be most difficult to learn (and that instructors found most difficult to teach). These pain points were specifically addressed in game design, particularly since the videogame format allows students to explore and play with these challenging concepts in ways that are otherwise not possible using other more traditional forms of instruction.

## Full immersion

# 95%

**of all recorded behaviors and communication were related to active discussion of the game and science problems**


» *Sample treatment from the art slam: Martha Madison's lab*

### Art Slam

Because the art and graphics of the *Martha Madison* games are the first point of entry into learning, it was essential to examine the aesthetic preferences of the target audience. In addition to appealing to middle school students of both genders, the aesthetics also needed to allow for accurate depictions of scientific content across multiple hardware platforms. To help establish and evaluate the concept art for the digital facets of the curriculum, Second Avenue Learning held an "art slam" with middle school students from urban, suburban, and rural school districts.

## Quick study

**Significant increases in content recognition were found after just one 25-minute play session**

Prior to the art slam, several artists created sample art treatments for the project. Each artist was tasked with reading a creative brief and designing the Martha Madison character, an additional playable animal, Martha Madison's lab, and one outdoor level. Middle school participants reviewed each of the five resulting art treatments, rating each component using a Likert scale (1-5). In addition, each art treatment was presented to game design faculty at New York University and the Rochester Institute of Technology. Based on the data and feedback gathered during the art slam, two treatments were selected to serve as design guides for the remainder of the games.

### Playtesting

Playtesting is a form of research commonly used by game designers in order to answer key design and functionality questions, such as:

- Does the game function as intended?
- Are there any technical barriers or bugs that prevent players from engaging in learning or play?
- Do players use mechanics in unexpected ways? Can these ideas be incorporated into the game?

Playtesting may be conducted as a formal study, though more often it involves an informal observation of gameplay. Second Avenue Learning has playtested all *Martha Madison* games (*Simple Machines*, *Optics*, *Forces*, and *Waves*) throughout the development process, from the paper prototype stage to the finished product. During each playtesting session, a cross-disciplinary team of observers (artists, developers, learning designers, and researchers) examines how testers progress through a game, taking note of any issues, gaps, or indicated changes. Because *Martha Madison* is a collaborative educational game, observers also collect data on student communication, problem-solving strategies, and overall peer engagement.

**"I liked that you have to use your mind to make it work. It was really fab! I hope to play it again."**

8th-grade playtester

The information gathered during playtesting is used to refine the game and resolve technical issues. In addition, playtesting has frequently uncovered new opportunities or ideas for future features. For example, playtesting sessions for the *Simple Machines* and *Optics* games revealed that testers desired more opportunities to create their own puzzles; this led to the creation of a maker space, in which students use a simplified level editor to build playable game levels. Playtesting of the maker space has in turn led to other discoveries, such as its potential use as a game-based formative or summative assessment.

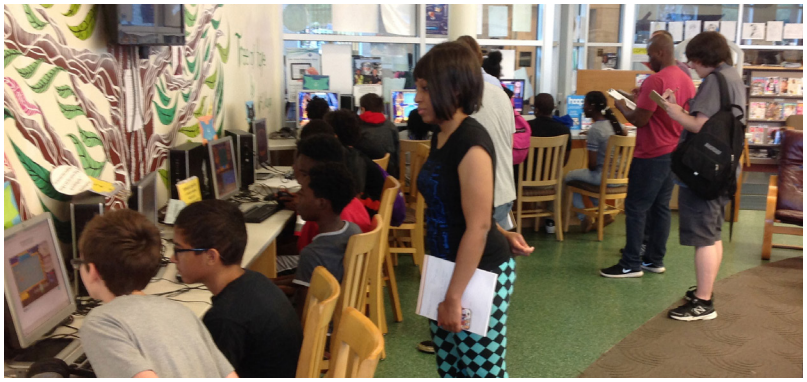
### Quasi-experimental Pilot Study: Simple Machines

To formally examine the effects of the *Martha Madison's Marvelous Machines* game prototype on student outcomes, Second Avenue and faculty from the Rochester Institute of Technology conducted a mixed method study with middle school participants from rural, suburban, and urban districts. This study was designed to investigate how the simple machines game influenced students' content learning, engagement, communication, and collaboration.

All participants took part in two research sessions which occurred in a lab at the Rochester Institute of Technology. Both sessions were designed to fit within the time frame of a typical middle school period. During the first session, demographic and technical literacy data was collected, along with survey data pertaining to participants' perceptions of the STEM disciplines. A content pre-assessment was completed at the end of this session. The second session took place in the same lab. During this session, participants were paired and asked to play through the four levels of the Simple Machines game prototype. Following the play session, students completed a post-survey of STEM perception as well as a content post-assessment.

**"This would be a great homework assignment."**

8th-grade playtester



» *Playtesting* Martha Madison: Optics *in upstate New York library*

## Mind the gap

**95%**

**of the STEM affiliation gap was closed by minority and economically-disadvantaged students in comparison to their majority peers**

A substantial gap in STEM discipline perception and affiliation was observed prior to the intervention; notably, students from urban districts demonstrated lower perceptions of the STEM fields (mean score = 49.7 out of 100) than students from rural or suburban districts (means of 75.3 and 72.7, respectively). After playing the Martha Madison game, however, students from urban districts demonstrated a significant increase in positive STEM discipline perception and affiliation after playing the game (mean = 69.9), effectively closing the gap between themselves and their rural and suburban peers.

While analyses of content learning indicated positive trends in concept understanding and exploration, results suggested that students experienced difficulty in understanding the specialist vocabulary of the standardized test items included on the assessment. This barrier may have prevented students from more fully demonstrating their comprehension of the science concepts, simply because students did not recognize terminology as representative of what was seen in the game.

Analyses of qualitative data indicated that the *Simple Machines* game encouraged positive, collaborative communication that was highly focused on game play. Nearly 95% of all recorded behaviors and communication were related to active discussion of the game and science problems, indicating that students were deeply immersed and focused on the academic content and problem-solving. Negative behaviors or statements were only rarely recorded (2.75% of all coded segments).

Students playing *Simple Machines* chose to replay levels an average of 5.1 times. This finding indicates that the exploratory design of the game not only engaged and motivated students, but also prompted them to identify multiple solutions to the challenges presented in the game.

## Play it again

**Students chose to replay levels an average of**

**5.1 times**

The results of this study, as well as the collected results of multiple playtesting studies, led to a number of significant changes in the games. For example, each game now integrates specialist science vocabulary throughout play, so that students can connect terminology with concepts. The game maker space was also developed as a result of participants' expressed desires to create content of their own.

**"The game is fun because you need to figure out what to do and test different combinations."**

8th-grade playtester

### Classroom Studies (ongoing)

Second Avenue Learning is currently conducting ongoing classroom studies to investigate student outcomes and gather teachers' feedback on the *Martha Madison* games. The classroom studies, utilizing the fully-developed *Optics* and *Forces* games, are being conducted with eighth-grade students. Some studies are utilizing a rigorous randomized control design, meaning that students are randomly assigned to either a treatment group (playing the game) or a control group (taking part in more traditional school activities). Students in both groups are exposed to the same content; for example, students in the treatment group solve problems in the game involving levers, while students in the control group solve the same type of problem on paper after watching an instructional video and listening to a brief lecture. Other pilots utilize other research designs, all using pre- and post-test data collected before and after students play the games. Below is a sample report from a recent exploratory study.

### Exploratory Field Study (New York)

***Participants and Implementation:*** Second Avenue Learning partnered with a middle school in upstate New York to conduct a small exploratory field study of *Martha Madison: Optics*. A total of 73 student participants between the ages of 13 and 14 volunteered to take part in the investigation; of these, 62 completed the entire protocol. The purpose of the study was twofold: (1) to examine the effects of playing *Martha Madison* on student content learning, and (2) to complete a larger scale technical and implementation test of the game in an authentic educational setting.

Results of this exploratory study are promising, and highlight how playing *Martha Madison* can improve students' content learning, as well as their feelings of self-efficacy and affiliation with STEM (the latter two factors have been the focus of earlier studies of the games). In the current study, students were asked to complete a pretest of key content knowledge measures in optics. The pretest included items that assessed recognition and understanding of scientific terminology (e.g. defining and describing a convex lens) and items examining concept recognition (e.g. identifying the phenomenon of a pencil appearing to bend in a glass of water as an example of refraction).

**"I really like that this game is more friendly to play with someone else"**

8th-grade playtester

A total of 73 students completed the pretest. None of the students had received prior instruction in principles of optics. A day after completing the pretest, students took part in a classroom testing session during a 45 minute science class period, in which they played through the first five levels of the Optics game. The game is designed to encourage students to explore, play with, and solve problems using key concepts, prior to any informal instruction. As such, students encountered the concepts of reflection, refraction, dispersion of light and component colors, convex lenses, concave lenses, and prisms in the game. However, students did not receive any formal instruction, either before, during, or after the study. Due to district scheduling restrictions, it was necessary to postpone the posttest content measure for two weeks. Of the 73 original participants, 62 completed the posttest measure.

***Analysis:*** Due to the sample size, results of the field study were analyzed with a cutoff of $p = 0.10$ for statistical significance. Analyses of the data demonstrate that playing the game had positive effects on content learning. Students' mean score on the pretest was 4.44 ($SD = 1.44$), and the mean score on the posttest was 4.81 ($SD = 1.32$); $t = 1.54$, $p = 0.1$. Performance on the concept recognition measure reached statistical significance, with pretest mean scores of 1.96 ($SD = 0.80$) and a posttest mean of 2.26 ($SD = 0.68$); $t = 2.32$, $p < 0.02$. Mean scores for the scientific terminology measure were 1.94 ($SD= 0.94$) on the pretest and 2.06 ($SD = 0.99$); $t = 0.72$, n.s. on the posttest.

## As I recall . . .

**Ø teacher-led, classroom instruction;**

**10% increase in concept recognition**

***Conclusion:*** After a single short play session with *Martha Madison: Optics*, students demonstrated improvements in content learning. These results are especially remarkable when considering that students did not receive any direct instruction from the teacher. Moreover, these effects were found after a two-week delay with no instruction or review, suggesting that content encountered during gameplay was effectively transferred to long-term memory, likely due to the game's learning-aligned mechanics, adaptive feedback, and personalized, collaborative approach to authentic STEM problem-solving.

## Future Research

In addition to conducting additional controlled and exploratory field studies with the *Simple Machines* and *Optics* games, Second Avenue Learning aims to continue this line of research with the *Forces* and *Waves* games, as well as all other games that are developed as part of the suite. Additional measures of transfer and application are currently under development. A supplementary study of teacher fidelity (how teachers use the games, dashboards, and instructional materials) will be conducted at a future date.

> **"I hope one day everyone will be able to play this game."**
>
> 8th-grade playtester

**SECOND AVENUE LEARNING**

Founded in 2006 by Victoria Van Voorhis, Second Avenue produces educational games for learners of all ages. Driven by research, the company is focused on making learning playful and fun, opening pathways to success for all students to become innovators. The company's rich portfolio encompasses custom software design and development for K-16 publishers and online schools, as well as direct-to-consumer apps and games.

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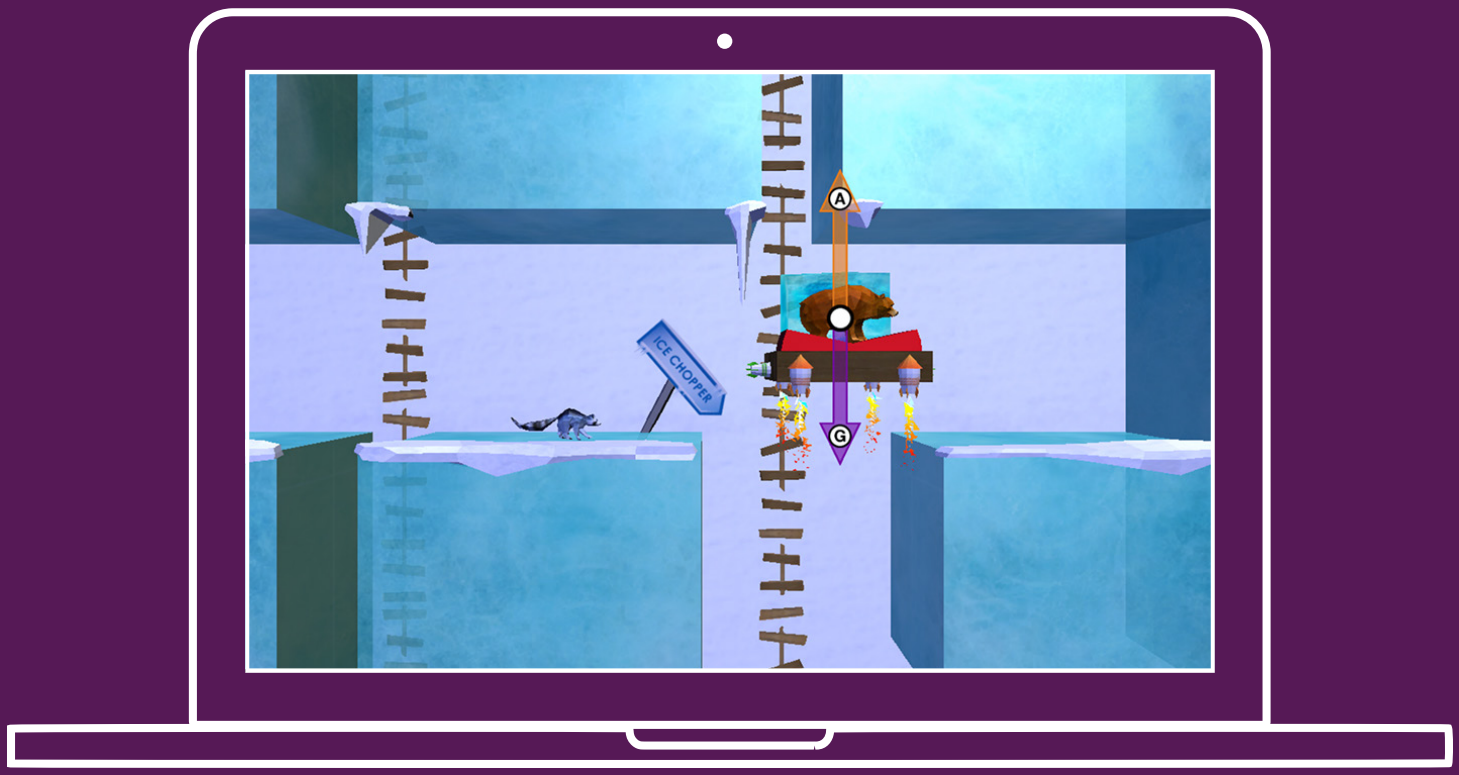


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