Understanding Physics through Collaborative Design and Play:

Integrating Skateboarding with STEM in a Digital and Physial Game-Based Children's Museum Exhibit

Summative Report

NSF Grant #1611685

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Summative Report (September 1, 2016 through August 31, 2021)

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This summative report reflects the collaboration between academic research and practical application of STEM concepts in a children's museum environment, and it documents learned practices for designing museum exhibits to engage young children and their families. The project was funded on a 3-year timeline and followed by 2 years of no-cost extensions that were complicated by ongoing challenges related to the COVID-19 pandemic.

Overview

The Iowa Children's Museum exhibit designed and created as a result of this grant, "The Science of Skateboarding," integrates skateboarding and STEM in an engaging context for youth ages 5 to 8 to learn about Newton's Laws of Motion and to connect traditionally underserved youth from rural and minority areas through comprehensive outreach. The exhibit design process drew upon research in the learning sciences and game design, science inquiry and exhibit design, and child development scholarship on engagement and interaction in adult-child dyads. Overall, the project "Understanding Physics through Collaborative Design and Play: Integrating Skateboarding with STEM in a Digital and Physical Game-Based Children's Museum Exhibit" accomplished three primary goals. First, we planned, prototyped, fabricated, and evaluated a game-linked design-and-play STEM gallery presented as a skatepark with related exhibits for adult-child interaction in the Iowa Children's Museum. Second, we engaged in a range of community outreach and engagement activities for children traditionally underserved in the Museum. We developed and disseminated resources for children to learn about the physics of the skatepark exhibit without visiting the Iowa Children's Museum physically. For example, balance board activities were made portable, the skatepark video game was produced in app and web access formats, and ramps were created from block sets brought to off-site locations. Third, we conducted a range of research to better understand adult-child interactions in the skatepark exhibit in the Museum and to explore learning of physics concepts during physical and digital play. Our research findings collectively provide a new model for Children's Museum exhibit developers and the informal STEM education community to intentionally design, evaluate, and revise exhibit set-up, materials, and outcomes using a tool called "Dimensions of Success (DOS) for Children's Museum Exhibits." Research also produced a tool for monitoring the movement of children and families in Museum exhibit space, including time on task with exhibits, group constellation, transition time, and time in gallery. Several studies about adult-child interactions during digital STEM and traditional pretend play in the Museum produced findings about social positioning, interaction style, role, and affect during play.

The Science of Skateboarding exhibit at the Iowa Children's Museum

What were the major objectives and goals of the project?

The complete project had three broad objectives to build knowledge with respect to advancing Informal STEM Education:

1) Plan, prototype, fabricate, and document a game-linked design-and-play STEM exhibit for multi-generational adult-child interaction utilizing an iterative exhibit design approach based on research and best practices in the field;

2) Develop and disseminate resources and models for collaborative play-based exhibits to the informal STEM learning community of practice of small and mid-size museums including an interactive, tangible tabletop design-and-play game and a related tablet-based game app for skateboarding science and technology design practice;

3) Conduct research on linkages between adult-child interactions and game-connected play with models in informal STEM learning environments.

Three project goals linked to these objectives:

1) Develop tools to enable children ages 5-8 to collaboratively refine and test their own theories about motion by exploring fundamental science concepts in linked game and physical-object design challenge which integrates science (Newton's Laws of Motion) with engineering (iterative design and testing), technology (computational models), and mathematics (predictions and comparisons of speed, distance, and height). [Linked to Objectives 1 & 3]

2) Advance the informal STEM education field's understanding of design frameworks that integrate game environments and physical exhibit elements using tangibles and playful computational modeling and build upon the "Dimensions of Success" established STEM evaluation models. [Linked to Objectives 1 & 2]

3) Examine methods to strengthen collaborative learning within diverse families through opportunities to engage in STEM problem-based inquiry and examine how advance training for parents influences the extent of STEM content in conversations and the quality of interactions between caregivers and children in the museum setting. [Linked to Objectives 1 & 3]

The exhibit, "The Science of Skateboarding" at the Iowa Children's Museum, was designed and created as a result of NSF award #1611685. The exhibit integrates skateboarding and STEM in an engaging context for youth ages 5 to 8 to learn about Newton's Laws of Motion. The exhibit design process drew upon research in the learning sciences and game design, science inquiry and exhibit design, child development, and adult-child engagement and interaction.

"The Science of Skateboarding" exhibit opened to the public starting June 5, 2018. Iterative design improvements for the exhibit were completed by December 2019. In every year of the project, outreach programming connected traditionally underserved youth from rural and minority areas through comprehensive programming across Iowa. Beginning in early March 2020, the Iowa Children's Museum first closed its door to the public due to safety concerns resulting from the Covid-19 pandemic, and experienced intermittent interruptions in access after that time. The Museum's attendance numbers dropped dramatically due to the pandemic.

Broad Objective #1: Plan, prototype, fabricate, and document a game-linked design-and-play STEM exhibit for multi-generational adult-child interaction utilizing an iterative exhibit design approach based on research and best practices in the field.

Exhibit design and development occurred mostly in the first two years (2016-2018) of the project with the exhibit opening to the public in May, 2018.

The first broad goal (year one) was to finalize development of the Exhibit Design Plan working with the design team, advisors, and local consultants. To do this, a Mind Map diagram was created to visually identify exhibit goals and key STEM concepts and ten interactive exhibit components in a hierarchical fashion to guide the exhibit design process. Then, a finalized exhibit elements list was created along with three-dimensional mock-ups of the physical layout.

To accomplish the work, a cross-disciplinary Exhibit Design and DevelopmentTeam was formed. This team met 11 times in year one to plan, prototype, and document the exhibit design process. The Team included the Co-Is, Science Consultants, University Graduate Students, Museum Staff, Community Members, a Regional Advisory Committee, an External Advisory Committee, and High School Students. Uniquely, the Iowa Children's Museum partnered with local high school physics and arts classes from Iowa Big (a project-based high school) to involve youth with the exhibit design process. It was important to include representatives from community organizations on the exhibit design team to enable the project to establish ownership from the greater community. In addition, the Design Team adapted the Dimensions of Success STEM Evaluation tool created by the PEAR Institute to guide the process.

Also in year one, Exhibit Design Consultant Ingrid Kanics (Kanics Inclusive Design Services) was contracted to work with the project exhibit design team to evaluate exhibit activities in terms of physical and developmental accessibility. The training Kanics provided positively impacted this project's design as well as helped to train the museum staff in accessibility best practices.

Eight exhibit components were designed and either fabricated or purchased for the exhibit:

1) Magnetic Ramp Wall, purchased at http://kodokids.com/museum-magnet-wall
2) Rolling Ball Interactive Sculpture, fabricated by Rolling Ball Interactives, http://www.rollingballsculpture.com
3) Balance Boards, fabricated by McDonough Structures, Iowa City
4) Modular Skate Park Build, fabricated by McDonough Structures, Iowa City
5) Skate Shop, fabricated by McDonough Structures, Iowa City
6) Race Tracks, purchased from Best Tracks, http://www.besttrack.com with structural modifications made by McDonough Structure, Iowa City
7) Friction Hill, fabricated by McDonough Structures, Iowa City
8) Gaming Touch Tables (2) with skatepark software designed by RevUnit, http://revunit.com

#1 Magnetic Wall

#2 Rolling Ball Sculpture

#3 Balance Boards

#4 Modular Skatepark Build

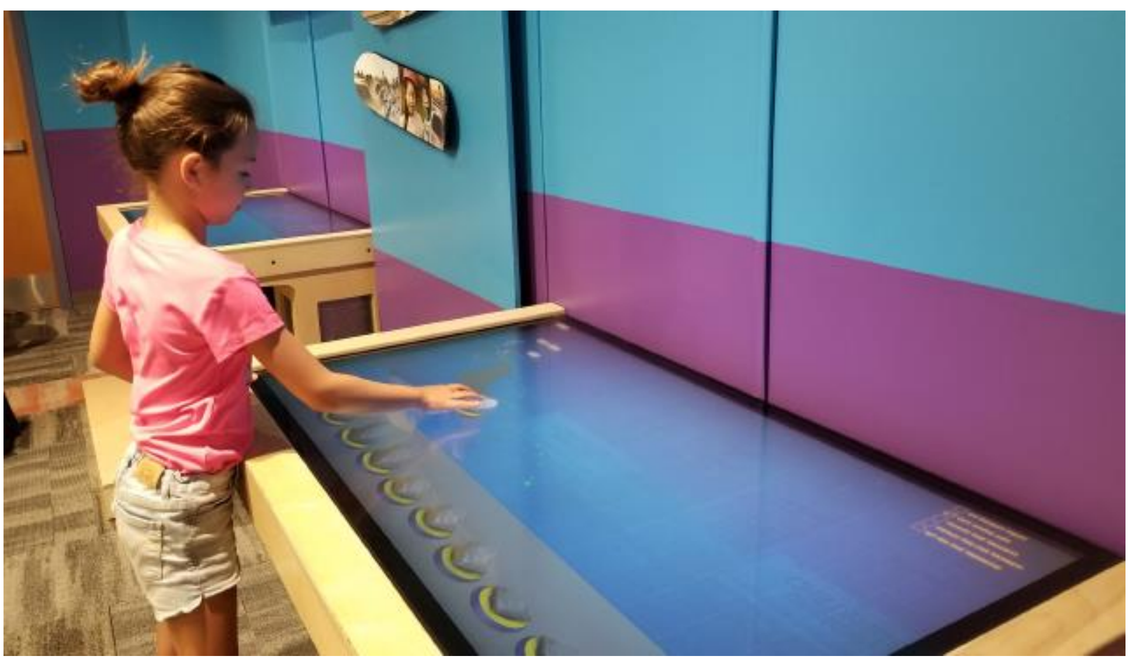
#4 Modular Skatepark Build

#5 Skate Shop

#6 Race Tracks

#7 Friction Hill

#7 Friction Hill



#8 Gaming Touch Tables

#8 Gaming Touch Tables

The second broad goal (year one) was to test exhibit prototypes. Throughout, the design team tested ideas of exhibit components, design art, art style, development of play, placement and interaction of exhibit components, and so on. Because some of the exhibit components were fabricated or modified in-house (e.g., "Modular Skate Park Build," "Race Tracks," " Friction Hill") or part of a separate consultation (e.g., "Touch Table Skatepark Software"), preliminary user testing with these exhibit components began as early as April 2017.

In May 2017, we began user testing of the alpha prototypes with children in the targeted age range. We hosted focus groups with parents, children, educators, childcare providers, and community organizations.

Eight exhibit components were either fabricated or purchased for the exhibit and put into use in a new gallery at The Iowa Children's Museum called "The Science of Skateboarding." The exhibit opened to the public in May 2018, almost two years after design had begun.

In the following year (year three), each exhibit component underwent iterative design changes and improvements with the goal of making exhibit interactions more meaningful in helping children gain improved STEM understanding.

<u>Broad Objective #2</u>: Develop and disseminate resources and models for collaborative play-based exhibits to the informal STEM learning community of practice of small and mid-size museums including an interactive, tangible tabletop design-and-play game and a related tablet-based game app for skateboarding science and technology design practice.

This project developed three primary novel resources and models by creating the DOS STEM Exhibit Development Analysis Tool for children's museums, creating digital tabletop and tablet-based games for collaborative play and STEM learning, and engaging communities through outreach dissemination.

<u>Developing the DOS STEM Exhibit Development Analysis Tool</u>

First, an adaptation of the PEAR Institute's Dimensions of Success (DoS) STEM Program Quality Assessment Tool was created to be used for STEM exhibit development and evaluation. This adaptation, the DOS STEM Exhibit Development Analysis Tool, has nine dimensions that were identified and defined as relevant and meaningful for use in exhibit evaluation: 1) STEM Learning Goal, 2) Alignment to Standards, 3) Targeted STEM Concepts, 4) Dimensions of Success Analysis, 5) Measurable Outcomes of Goals, 6) Accessibility and Inclusiveness, 7) 21st Century Skill Development, 8) Diverse Learning Styles, and 9) Level of Play and Enjoyment. Each of the "Science of Skateboarding" exhibit components was subjected to analysis with the 9 DOS dimensions for evaluation and redesign. Oversight of this process was provided by PEAR Institute's Dr. Ashima Shah, who is also on the project's External Advisory Board.

Several activities contributed to revision and application of the DOS for use with exhibits. In the initial year of the project (2016-2017), the exhibit design team consulted with Dr. Ashima Shah from the PEAR Institute, and met with our External Advisory Board in the spring and in the fall for feedback on exhibit design. We used the PEAR institute's twelve dimensions of high quality STEM education to guide design discussion and problem-solving: 1) Features of the Learning Environment: Organization, Materials, Space Utilization, 2) Activity Engagement: Participation, Purposeful Activities, Engagement with STEM, 3) STEM Knowledge & Practices: STEM Content Learning, Inquiry, Reflection, and 4) Youth Development in STEM: Relationships, Relevance, Youth Voice.

The final product was tested iteratively in our exhibit and shared broadly in the following ways:

1) PI Dunkhase presented the DOS STEM Exhibit Development Analysis Tool at the Iowa STEM Advisory Council's state-wide STEM Professional Development week-long training in July 2017 with both formal and informal STEM educators.

2) PI Dunkhase and Co-PI Missall presented the tool in May 2018 at the annual meeting of the Association of Children's Museums with children's museum staff from across the United States to encourage using this method in other informal STEM learning environments. Related, the tool was presented at the 2018 Association of Science and Technology Centers in Hartford, CT to a crowd of about 40 museum professionals.

3) The Imagine Children's Museum from Washington State contacted grant PIs for training to use the DoS tool for exhibit design in a 25,000-foot expansion at their children's museum.

4) In 2019 PI Dunkhase delivered professional development at the University of Iowa's Belin Blank Center for Gifted and Talented to 30 formal education teachers to provide training on how STEM programs and active learning experiences are enhanced through alignment with the DoS tool developed by this project.

5) The DOS STEM Exhibit Development Analysis Tool was presented to the Iowa Governor's STEM Advisory Council Active Learning Group at meetings throughout the summer of 2019. At these meetings, it was determined that the state-wide Iowa Active Learning Community Partnership (i.e., The Iowa Children's Museum, The Science Center of Iowa, Blank Park Zoo, and the Iowa Afterschool Alliance) would work together to create 25+ STEM lesson plans designed using the *Dimensions of Success* (*DoS)* tool to disseminate to Iowa informal STEM program providers and exhibit developers. A protocol was established to guide the creation of 20+ lesson plans housed on the Iowa After School Alliance's website https://www.stemforiowa.org/. In addition, STEM professional development training that incorporated the DoS exhibit design used in this NSF grant project was designed and delivered to STEM practitioners throughout the state during 2018 and 2019. This professional developent model continues to be offered through the Iowa Afterschool Alliance's website at https://www.stemforiowa.org/professional-development

THE IOWA CHILDREN'S MUSEUM
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Development Process: NSF Skateboarding Exhibit	
Exhibit Component	**Balance Boards**
EXHIBIT LEARNING GOAL	**The physical experience of trying to balance on the Balance Board scaffolds understanding of the concepts of center of gravity and balance.**
Exhibit Environment Description	Several (3) balance boards will be available for kids to explore and experiment with using their bodies to test the concepts of balance and how it's impacted by center of gravity. Boards are placed in front of large mirrors so kids can observe cause and effect of body movement. Visual representations of skateboarders will be on display in various body positions to challenge exhibit users to "test" different body positions on the Balance Boards. Visual representation of where Center of Gravity is on a skateboarder will also be displayed.
How does the exhibit meet Next Gen Science Standards?	Next Generation Science Standards: **PS2.A: Forces and Motion** Third grade: • Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause change in the object's speed or direction of motion. • The patterns of an object's motion in various situations can be observed and measured; when the past motion exhibits a regular pattern, future motion can be predicted from it. **PS2.B: Types of Interactions** Third grade: • Objects in contact exert forces on each other. Fifth grade: • The gravitational force of Earth acting on an object near Earth's surface pulls that object toward the planet's center. **PS3.C: Relationship Between Energy and Forces** Fourth grade:

Example of DoS Exhibit Development Analysis for the Balance Board Exhibit (1st page)

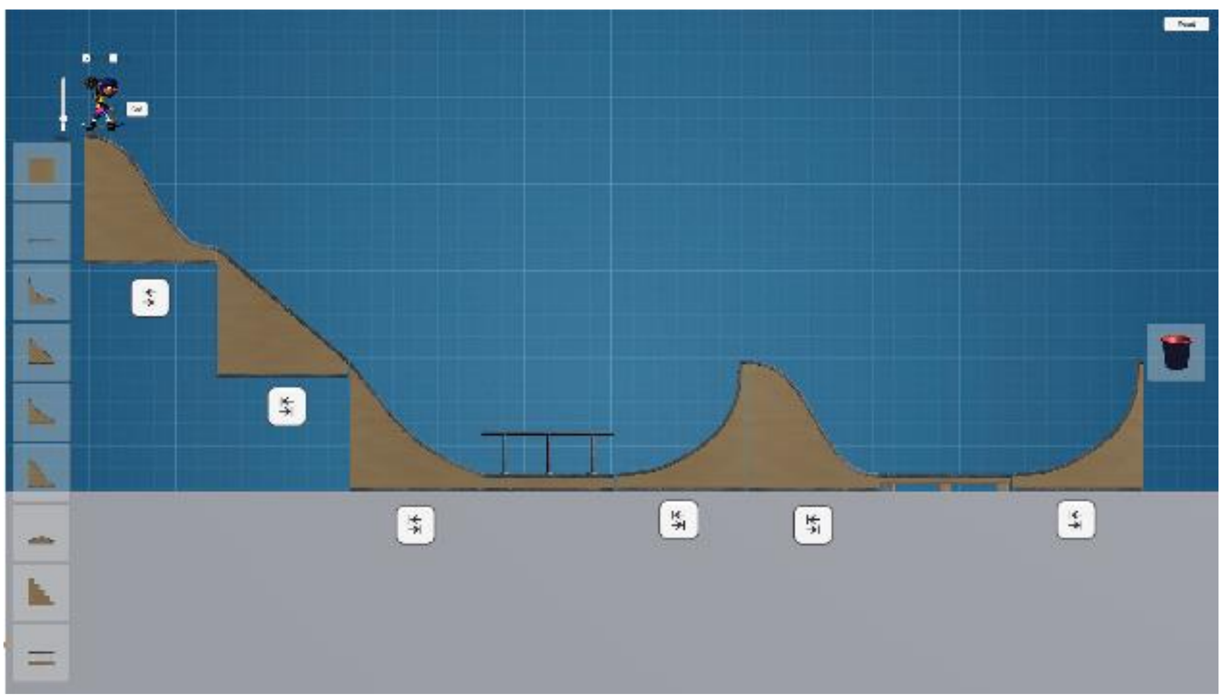
Creating Digital Tabletop and Tablet-Based Games for Collaborative Play and STEM Learning

One of the exhibit components, the two Gaming Touch Tables with software designed by RevUnit, http://revunit.com, were selected specifically to test hypotheses about physical to digital learning via intergenerational collaborative play. Given that the outcome of the exhibit component was essential to project research questions, special attention was given to iterative exhibit design. The software would be designed to allow users to create a digital skatepark for an avatar to test. Users would apply knowledge learned throughout the exhibit about friction, mass, momentum, gravity in interactions with physical 3-dimensional objects to a digital, 2-dimensional game.

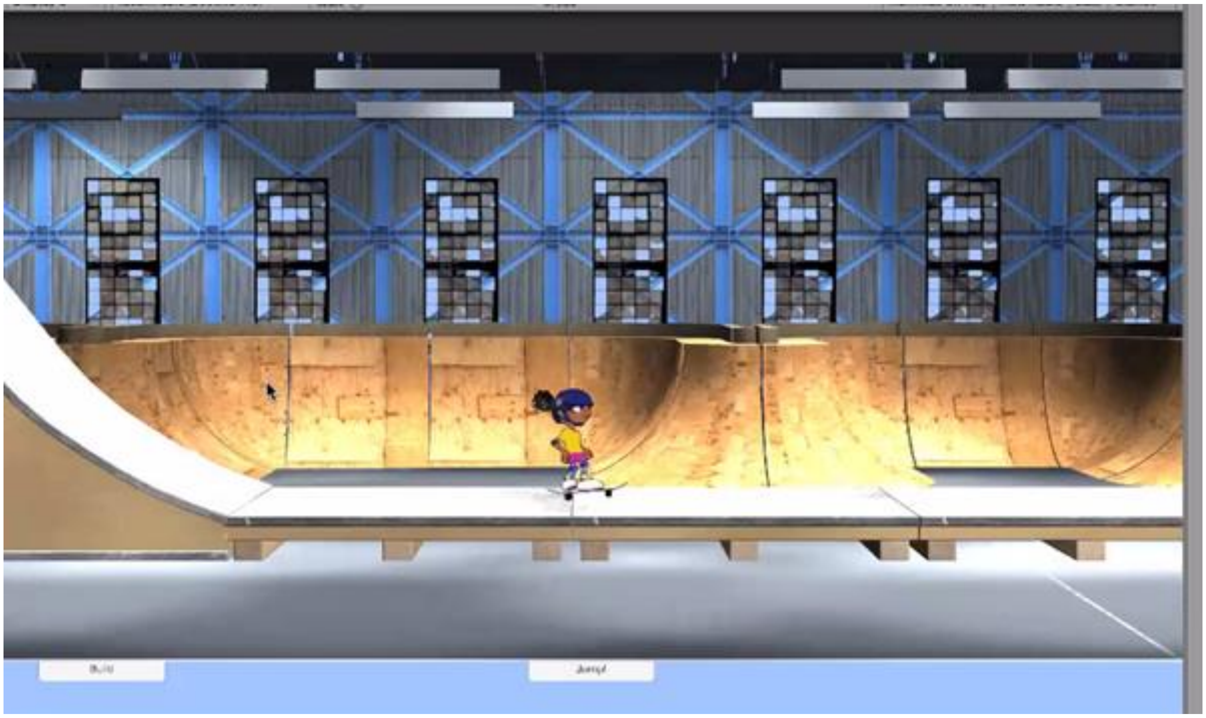
In year one, we collaboratively prototyped and designed the interactive tabletop game mechanics, aesthetics and interfaces with software developer RevUnit. We held bi-weekly meetings to discuss interaction design of game design, creation and user testing of design metaphors, testing of art style, development of play prototypes. Using high-quality maps and mock-ups of the physical layout of the exhibit and physical prototypes ("Modular Skate Park Build") as early as spring 2017, an "alpha" game prototype was produced in May 2017.

Using one tabletop, we piloted the "alpha" build with parent-child dyads and collected observational and self-report information on use. As a result, aesthetics, mechanics and interfaces were altered significantly with software developer RevUnit in ways that were mostly adaptive (e.g., children couldn't easily reach the top of the touchtable) or intuitive (e.g., a trash can isn't needed when images can be "slid off" the screen).

In year two, after dozens of "child pilot tests" and updates, the skateboarding app was completed by RevUnit for installation into the exhibit. The two Gaming Touch Tables were ready for exhibit opening. These images show the sandbox mode (first image) where users create their skatepark, and the run mode (second image) where users see their build contextualized in skatepark art.



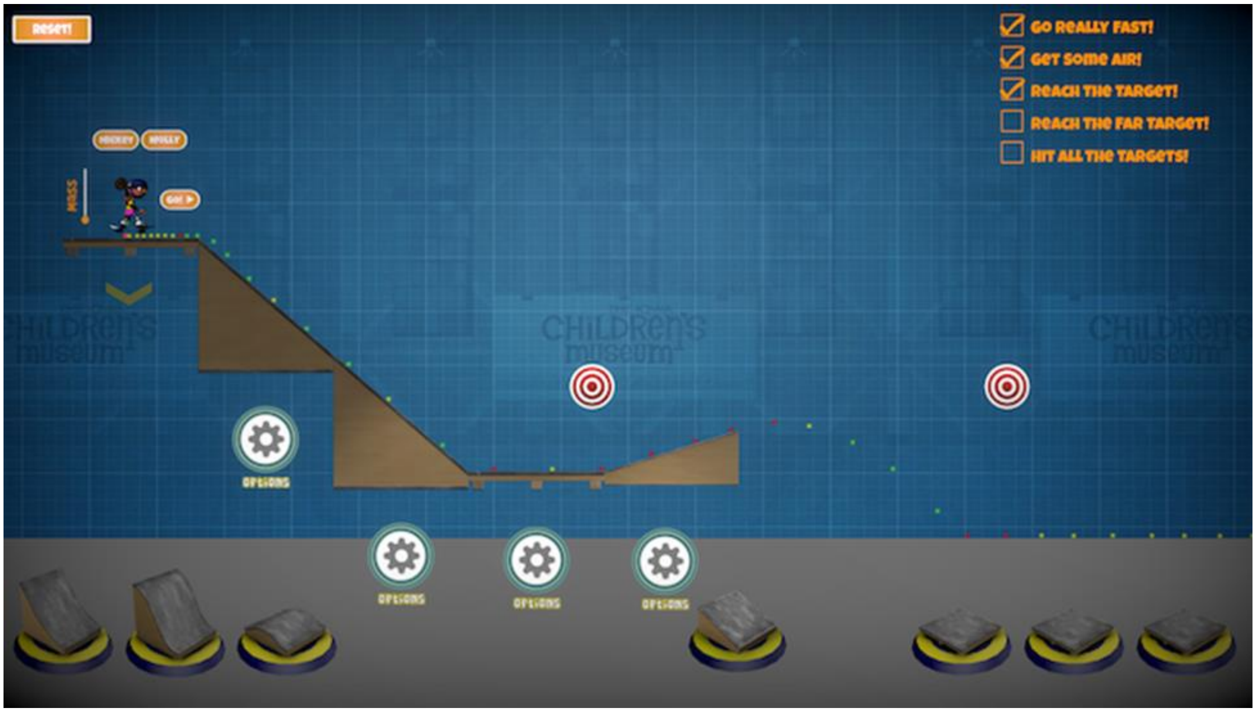
Sandbox Build Mode



Run Mode

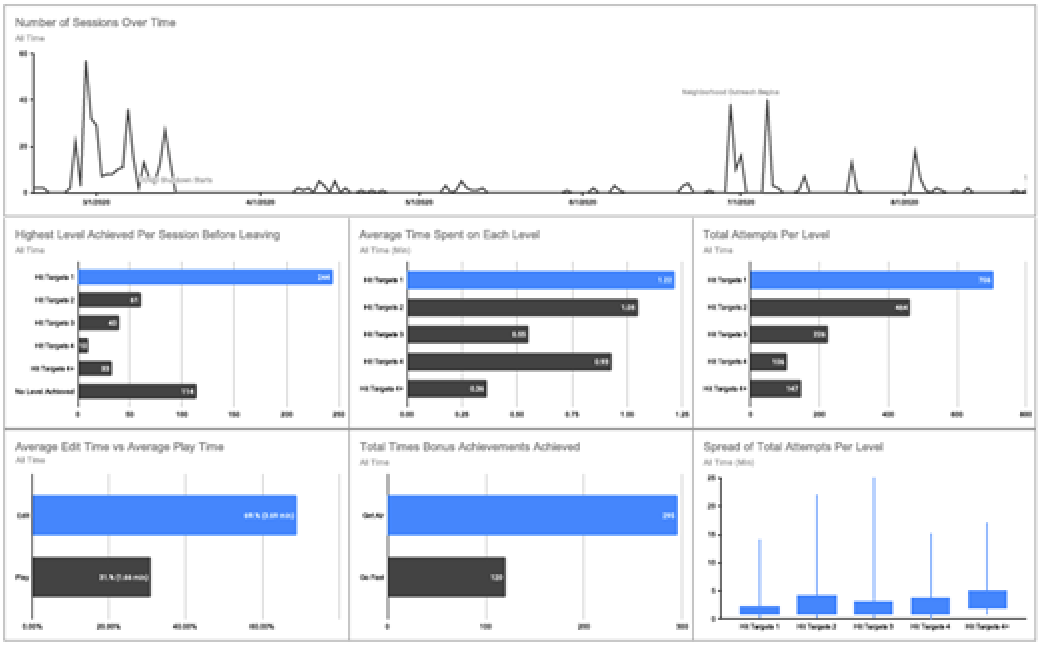
By year three, exhibit observation indicated users were not demonstrating sustained attention at the Gaming Touch Tables and user feedback indicated that the software was not sufficiently challenging. To address these issues, RevUnit added targets and text-based goals to the gaming app (see next image) to challenge youth users in particular to use their understanding of physics to achieve success in playing the game, greatly improving the amount of focused time students spent exploring this exhibit component.

During this time RevUnit also worked with us to build an app version of the tabletop software for download on handheld devices (e.g., iPads and iPhones). The app was used in two very important ways. First, the app allowed the Museum to transport the tabletop gaming experience to outreach reach on iPads. Second, a QR code to download the app on smartphones was available immediately at the Gaming Touch Tables in the exhibit. Caregivers and children downloaded the app for continued use and learning outside of the Museum environment.



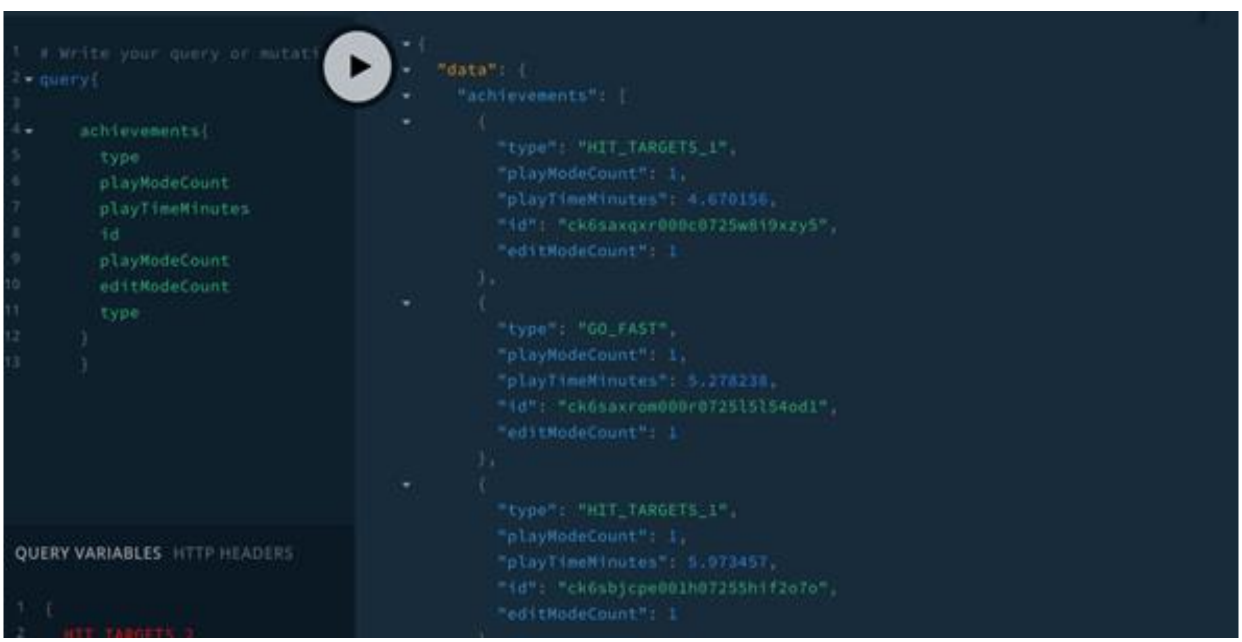
Software Build with Targets and Text-Based Challenges

In year four, we worked with RevUnit to create an algorithm to collect information about user's interaction with the tabletop game in the Iowa Children's Museum setting during typical game play during a museum visit. From September 1, 2019 through March 10, 2020, the new algorithm collected data about user interaction and generated a data display that is useful to both the research team and the children's museum. The next image shows an example of the Skateboarding App Data Dashboard.



Skateboarding App Data Dashboard

Working with RevUnit, we created a GraphQL schema that allows us to run real-time queries about user actions while they are playing the game.



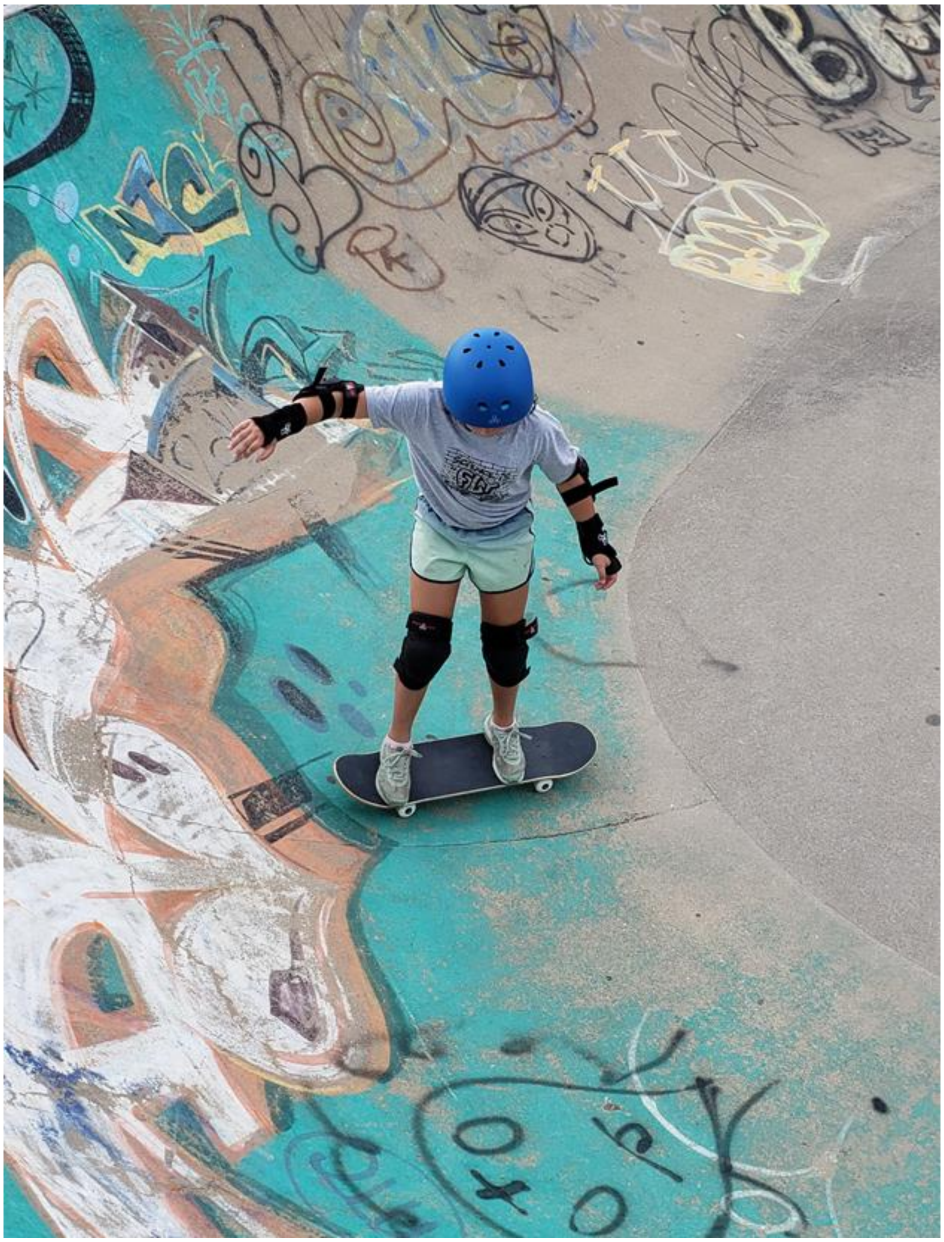
This data allows us to see the design of each user's skatepark when they reach an achievement, how long they spent creating that version of their skatepark, and how long they spent playing in their skatepark. We hope to use this data to be able to describe or assess players' design reasoning.

Engaging Community through Outreach Dissemination

Beginning in year three of the project (2018-2019), exhibit outreach from the Iowa Children's Museum began. Specifically, exhibit-associated programs were designed and successfully presented to school groups, summer camp participants, and through after school programs. Exhibit programs were also delivered through field trips and day camps with youth throughout the state of Iowa. Outreach programming was designed and implemented with a focus on local minority and low-opportunity communities to reach traditionally underserved populations. Specifically:

1) In August 2019, the Iowa City Community School District (ICCSD) hosted the inaugural Science of Skateboarding Summer Camp Program for Fifth Ward Saints North students. This camp enrolled a group of 25 of the most at-risk middle school students in ICCSD. The camp program enabled students to gain unique experiences with physics through interactions in the skateboarding exhibit, i.e. building skateboard ramp systems in the Modular Ramp Exhibit that would enable their skateboard to travel specific distances. After reaching their STEM goal within this experiential exhibit, the students were able to transfer their new knowledge to creating skatepark systems with the exhibit's digital app on the Tabletop Exhibit.
2) In 2019-2021 we collaborated with another local nonprofit, Open Heartland, to provide minority Latino and Black youth populations in Eastern Iowa with quality STEM active learning experiences. Throughout COVID-19 closures, the Museum continued to provide "Science of Skateboarding" STEM outreach activities for Latino immigrant students ages 5 through 12 living in severely economically disadvantaged mobile home communities in Eastern Iowa. The Iowa Children's Museum staff attended and supported 16 events that served 288 students with enriching STEM active learning experiences. The specific learning activities included: 1) Box Parties (cardboard builds with balls and ramps challenges), and 2) internet access and iPads with the project's skateboarding app were made available. In addition, this outreach activity greatly increased the database for the skateboarding app – an important activity with the museum closed due to COVID-19.
3) In 2020-2021, programming connected to this project and delivered by the Iowa Children's Museum from September 1, 2020 through August, 2021 reached 1,249 elementary students on field trips and participants in 25 day camps.
4) Statewide outreach programming included participation in two STEM festivals conducted by the Iowa STEM Council in central and eastern Iowa. STEM activities facilitated by The Iowa Children's Museum reached 125 individuals with hands-on skateboarding activities intended to promote both STEM knowledge and the desire to learn more about

the physics of skateboarding by visiting the exhibit at the museum. The Museum participated in one local community event, *Sand in the City*, reaching approximately 175 youth and their caregivers as they explored properties of materials and how these concepts relate to movement.



Fifth Ward Saints Summer Camp (#1 above)

Open Heartland Outreach (#2)

Open Heartland Outreach (#2)

Day Camp (#3)

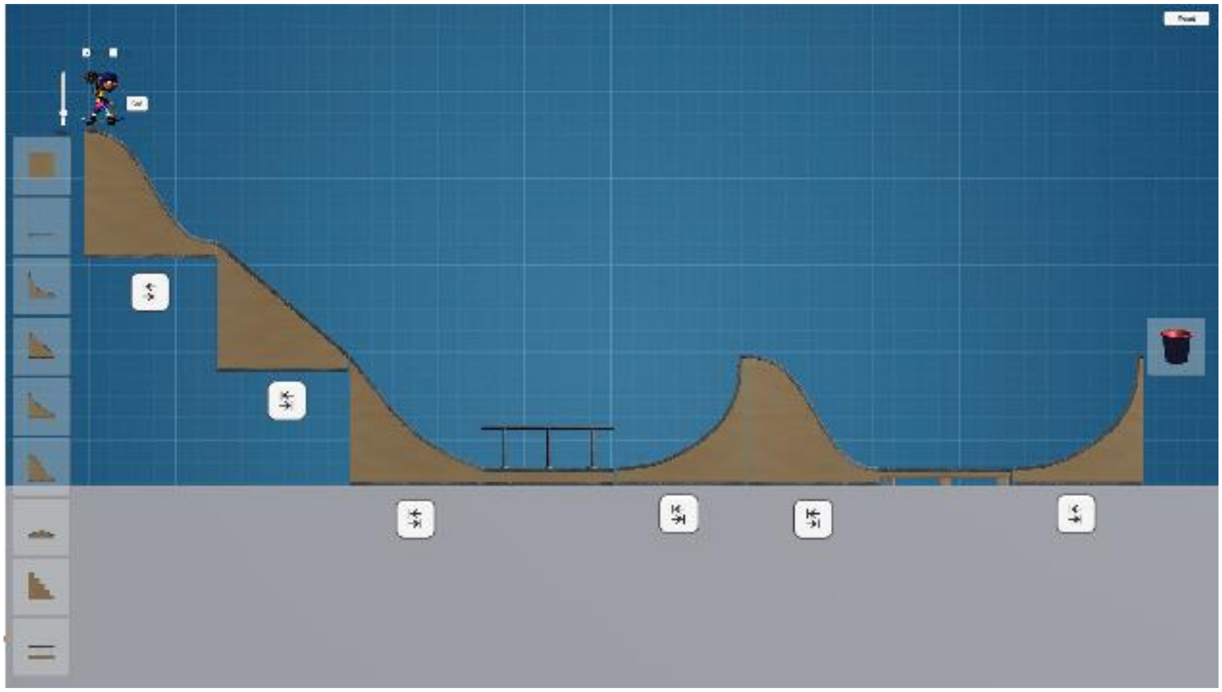
Day Camp (#3)

Broad Objective #3: Conduct research on linkages between adult-child interactions and game-connected play with models in informal STEM learning environments.

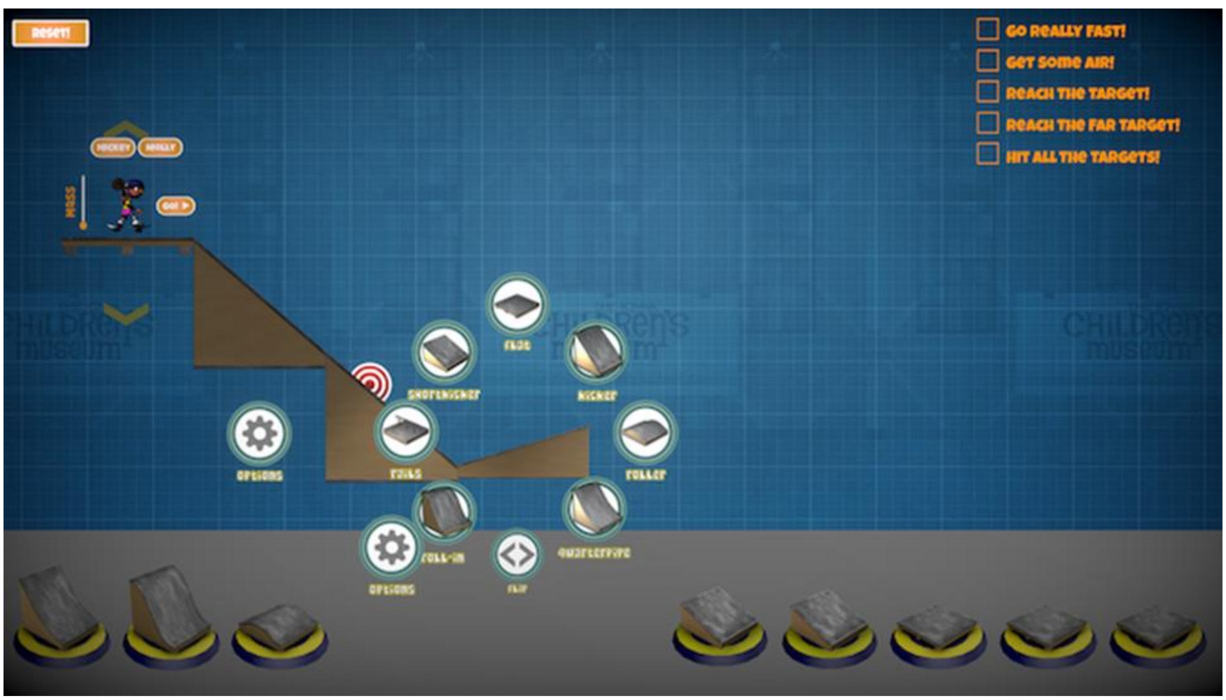
Research efforts began in year one with systematic literature reviews to support the development of observational codes for collaborative adult-child interactions and use of gaming interfaces. Several research literature bibliographies were completed, including: parent-child communication and interaction during collaborative digital play, family learning in museum settings, collaborative problem-solving with interactive tabletop interfaces, and content talk and learning during collaborative tabletop play. This work translated to a qualitative pilot study on collaborative play and problem-solving with adult-child dyads. Using the alpha prototype of the software for the Gaming Table Tops, we asked adult-child dyads to play the game. Play sessions lasted approximately 15-minutes, and were followed by a project-designed "close" transfer "show-and-tell" reflection activity for child participants to examine their reasoning processes in game play. We asked children to reflect on one of their builds and to show us how they created the digital skatepark using a 3-dimensional physical model. Simultaneously, we asked adults to complete project-developed surveys on beliefs and attitudes related to STEM and digital learning and experiences. Using video recordings of adult-child play sessions, we evaluated adult-child collaborative discourse during game play. Examples of parent-child interactions, challenges, and feedback were shared with RevUnit and several changes were made to the software related to interactive tabletop game mechanics, aesthetics and interfaces.

Throughout year two, "kid tests" continued to result in dozens of software updates. The Gaming Table Tops were made available to Museum visitors during the soft opening of the "Notion of Motion: Science of Skateboarding" STEM exhibit at The Iowa Children's Museum on May 1, 2018. The time allowed for contextualized observations and additional software modifications for one month prior to final installation of software and the exhibit Grand Opening on June 5, 2018.

In year three, user feedback on the Gaming Table Top indicated a need for additional challenges. Targets were added to the software. Direct observations in the exhibit setting showed that with the targets, children spent a longer and more focused amount of time at the Gaming Table Top exhibit. They tried more skatepark builds, spent more time on each build, and reasonably applied more hypothesis testing and application of physics principles. During this time, we also modified access to the ramp elements; they were originally presented to children on the left side of the tabletop and testing showed access needed to be easier and more accessible. Therefore, access was coded to appear as a pop-up wheel of choices with the placement of each new ramp element and hovering over the ramp (see two pictures below). We also built in features to rotate ramps because child users indicated an interest in using their mental rotation skills rather than being presented with every ramp option (see "<>" button on bottom image).

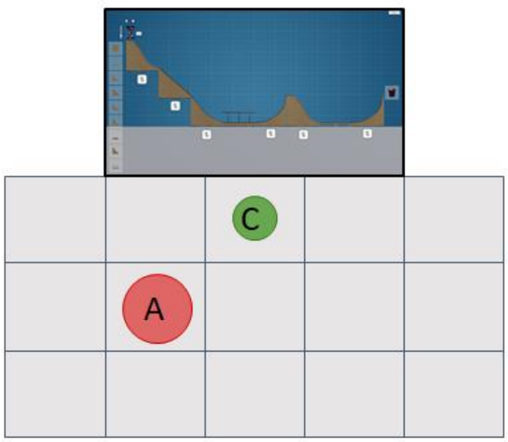


Ramp Selections Presented on Left Side of Touchtable



Ramp Selections Presented as a Pop-Up Menu with Hovering

In year three, we also examined collaborative play and use of the Gaming Table Top. First, we examined collaborative positioning around the multi-user tabletop (DeVane et al., 2017; Dietmeier, DeVane et al., 2017; Dietmeier, Miller et al., 2017; Gee et al., 2017) . By examining positioning, we were able to address questions about the extent to which play was child-or adult-directed. We created a grid to evaluate the location of the adult (red circle) and child (green circle) during play.



Positioning Grid for Evaluating Game "Driving"

Results showed that typically, when intervals of game play are coded for positioning, children stand still and adults move around them to reach the table. This finding likely has practical interpretations (e.g., it is easier to adults to reach the table from a further distance) and relational interpretations (e.g., adults let children drive the tabletop interactions and play). In fact, proximity during play was observed to be related to engagement and supportive interaction (e.g., scaffolding learning and game play).

	Child					
	A	B	C	D	E	
Edge	80	277	249	24	5	635
Touching	0	1	1	0	0	2
Arm Away	0	0	0	0	0	0
	80	278	250	24	5	

	Parent					
	A	B	C	D	E	
Edge	143	27	121	12	13	316
Touching	26	25	93	44	0	188
Arm Away	1	0	5	11	0	17
	170	52	219	67	13	

Children stand still (green squares showing limited movement across intervals) and adults move around them (yellow, orange, and red squares showing increasing movement across intervals).

Dyad B:
Sideline Observation

	P	C
QD	3	21
QO	21	1
AD / N	0	8
AO / N	3	3
G /S	5	0
D	1	0

Child				
A	B	C	D	E
0	18	64	0	0
0	0	0	0	0
0	0	0	0	0

Parent				
A	B	C	D	E
57	0	0	0	3
11	0	0	1	0
1	0	0	1	0

Dyad D:
Nearby Scaffolding

	P	C
QD	0	16
QO	0	2
AD / N	0	13
AO / N	21	2
G /S	13	0
D	0	1

Child				
A	B	C	D	E
46	51	3	0	2
0	0	0	0	0
0	0	0	0	0

Parent				
A	B	C	D	E
0	3	28	1	1
0	6	40	3	0
0	0	1	0	0

Adults who stood closer in proximity to children playing the tabletop game, tended to engage in more collaborative and supportive communication (see also DeVane, Dietmeier, Missall, Miller et al., 2019; Dietmeier et al., 2020).

Additional studies centered on the affect and content of adult-child interactions while playing the Gaming Table Top. A range of studies during tabletop play showed that parents tend to ask five times as many questions (2.50 questions/minute) as children (.47 questions/minute) during dyad play. Parents also tend to make about five times as many commands (2.75 commands/minute) as children (.50 commands/minute) during dyad play. Children did not respond to as many as 40%-51% of adult-generated questions and commands because there was no time before the next adult-generated question or command. At the same time an average of 34% of observed time was coordinated or joint adult-child play. This, together with findings about affect that indicated interactions had an overwhelmingly positive tone suggests that the high level of verbal interaction was indicative of engagement and play, rather than of instruction (see also Cox et al., 2020; Missall et al., 2018a; Missall et al., 2018b; Nanda et al., 2019). Another analysis of the content of verbal communication during adult-child dyad play at the tabletop indicated that talk centered on physics-related concepts 15%-33% of observed intervals with emphasis on motion (50%), potential energy (28.6%), gravity (14.3%) and force (7.1%; Missall et al., 2019).

Research questions also examined the movement of family groups in the "Science of Skateboarding" exhibit and their collaborative activity across the exhibit space. We developed a Qualtrics tool to allow us to track the movement and activity of family groups up to five across the exhibit space. We developed codes for each exhibit element, and also for spaces where visitors would congregate, as well as timestamps that described how long each member spent at a given location, when they arrived and departed. We also coded the activity of each family group member as participating through: a) Collective activity (all group members at a given element or space); b) Joint activity (two or more family group members at a given element or space); c) Separate activity (one family member apart from others). For each time period, the collective activity was multiplied by the number of group members, and joint activity was multiplied by the number of people at the relevant exhibit element. Adapting Horn et al's (2012) work on social balance, we calculated scores for collective activity balance and, when applicable, joint activity balance. This formula works out to the sum time in which each member of a group engaged in a particular form of activity divided by the total time spent in the exhibit (see Cox, 2020; Cox & DeVane, 2021).

Balance = (∑t_i)/((T* n)

	Groups of 2 (n=24)	Groups of 3 (n=33)	Groups of 4 (n=28)
Collective Balance	0.5744	0.5066	0.1081
Joint Balance	N/A	0.6817	0.8360

	1 - Page End	1 - Adult 1	1 - Child 1	1 - Child 2		2 - Page End	2 - Adult 1	2 - Child 1	2 - Child 2	2 - The group is done with the exhibi
S3	34.43	Central Seats	Friction Hill	Touchtable	J2S1	47.355	Racetrack	Racetrack	Touchtable	
C3	29.02	Skateshop	Skateshop	Skateshop	J2S1	21.047	Modular Ran	Modular Ran	Friction Hill	
C3	49.783	Racetrack	Racetrack	Racetrack	C3	32.829	Central Seats	Central Seats	Central Seats	The group is done with the exhibit
J2S1	41.023	Touchtable	Racetrack	Touchtable	J2S1	54.121	Touchtable	Racetrack	Racetrack	
S3	35.566	Front seats	Friction Hill	Skateshop		2.894				The group is done with the exhibit
C3	24.967	Skateshop	Skateshop	Skateshop	J2S1	54.373	Racetrack	Magnet wall	Racetrack	
	1 - Page End	1 - Adult 1	1 - Adult 2	1 - Child 1		2 - Page End	2 - Adult 1	2 - Adult 2	2 - Child 1	3 - Page End
J2S1	35.633	Central Seats	Ball Sculptur	Central Seats	C3	25.465	Racetrack	Racetrack	Racetrack	60.782
J2S1	47.288	Front seats	Front seats	Friction Hill	J2S1	41.556	Front seats	Ball Sculptur	Ball Sculptur	37.937
C3	66.819	Skateshop	Skateshop	Skateshop	C3	52.852	Central Seats	Central Seats	Central Seats	18.739
C3	41.397	Racetrack	Racetrack	Racetrack	C3	15.997	Friction Hill	Friction Hill	Friction Hill	2.07
C3	95.768	Modular Ran	Modular Ran	Modular Ran	C3	315.914	Racetrack	Racetrack	Racetrack	79.647

A Sample of Location/Activity Data

A final research project was established in years four and five during extensive Museum closures due to COVID-19. We worked with RevUnit, the developer of the skatepark software for the multi-user tabletop in the exhibit (Gaming Table Top), to create an algorithm to collect information about user's interaction with the tabletop game.

The new algorithm collected data about user interaction and generated a data display that is useful to both the research team and the Museum. We also worked with RevUnit, to create a GraphQL schema to allow us to run real-time queries about user actions while they are playing the game. The data from these programs allows us to see the design of each user's skatepark when they reach an achievement, how long they spent creating that version of their skatepark, and how long they spent playing in their skatepark. These data can be used to describe and assess players' design reasoning.

<u>Project Papers, Presentations, and Products</u>
(in chronological order; student names in italics)

Gee, E., Siyahhan, S., Tran, K. DeVane, B. *Dietmeier, J., Miller, B.J.*, Missall, K. *Nanda, S.,* Banerjee, R., & Yip, J. (August, 2017). *Intergenerational Game Play and Family Learning: Current Insights and Future Direction*s. Panel at the International Conference on the Foundations of Digital Games. Cape Cod, MA.

Dietmeier, J., DeVane, B., *Miller, B.J.*, Missall, K., & *Nanda, S.* (August, 2017). *Shredding with Mom and Dad: Intergenerational Physics Gaming in a Children's Museum.* Long paper at the International Conference on the Foundations of Digital Games. Cape Cod, MA.

Dietmeier, J., Miller, B. J., DeVane, B., Missall, K., & *Nanda, S.* (2017). Shredding with mom and dad: Intergenerational physics gaming in a children's museum. In S. Deterding, A. Canossa, C. Harteveld, J. Zhu, and M. Sicart (Eds.), *FDG '17 Proceedings of the 12th International Conference on the Foundations of Digital Games* (pp. 58-61). New York, NY: Association for Computing Machinery.

DeVane, B., Gee, E., Siyahhan, S., *Miller, B.J.*, Missall, K., *Dietmeier, J.,* & Nanda, S. (October, 2017). *Researching Intergenerational Learning In and Around Games.* Paper at the Conference on Digital Media & Learning. Irvine, CA.

Dietmeier, J., DeVane, B., *Miller, B.J.*, Missall, K., & *Nanda, S.* (October, 2017). *Drop into skatepark design: Connected family physics gaming in a children's museum.* Paper at the Conference on Digital Media & Learning. Irvine, CA.

Dunkhase, D., Mussman, A., & Missall, K. (2018, May). *New strategies for successful STEM exhibits.* Presentation at the annual meeting of the Association of Children's Museums, Raleigh, NC.

Missall, K., *Nanda, S., Courshon, C.*, DeVane, B., *Dietmeier, J., Miller, B.,* & *Brand, M.* (2018a, June). *Examining parent-child communication and affect during tabletop gameplay in a children's museum: Implications for learning.* Poster presentation at the International Conference on Learning Sciences, London, UK.

Missall, K., *Nanda, S., Courshon, C.*, DeVane, B., *Dietmeier, J., Miller, B., & Brand, M.* (2018b). Examining parent-child communication and affect during tabletop gameplay in a children's museum: Implications for learning. In J. Kay and R. Luckin (Eds.). *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (vol. 3, pp. 1747-1748). London, UK: International Society of the Learning Sciences.

DeVane, B., *Dietmeier, J.*, Missall, K., Miller, B., & *Nanda, S.* (2018). Dropping into game design: Iterations of a skatepark physics game for a children's museum exhibit. In J. Kay and R. Luckin (Eds.). *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (vol. 3, pp. 1349-1350). London, UK: International Society of the Learning Sciences.

Dunkhase, D. (2018). *New Strategies for Successful STEM Exhibits.* Presentation at the Association of Science and Technology Centers. Hartford, CT.

Missall, K. N., UW School Psychology Graduate Students, & Imagine Children's Museum (2018-present). *Play is learning blog.* Everett, WA. http://blog.imaginecm.org/

Nanda, S., Missall, K., *Courshon, C.*, DeVane, B., & *Dietmeier, J.* (2019, March). *Parent-child collaborative engagement during digital tabletop play in a children's museum.* Presentation at the biennial meeting of the Society for Research in Child Development, Baltimore, MD.

Missall, K., *Nanda, S., Courshon C.,* DeVane, B., & *Dietmeier, J.* (2019, March). *Learning physics in a children's museum: Examining parent-child communication during digital gameplay*. Presentation at the biennial meeting of the Society for Research in Child Development, Baltimore, MD.

DeVane, B., *Dietmeier, J.*, Missall, K., *Miller, B., Nanda, S.,* & *Courshon, C.* (2019, March). *More than standing around: Parent-child positioning informs collaboration during large-format gameplay*. Presentation at the biennial meeting of the Society for Research in Child Development, Baltimore, MD.

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Cox, M., DeVane, B., *Dietmeier, J.*, Missall, K., & *Nanda, S.* (2020). Characterizing parent-child communication, affect, and collaboration during multi-user digital tabletop gameplay. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2* (pp. 701-704). Nashville, Tennessee: International Society of the Learning Sciences.

Dietmeier, J., & DeVane, B. (2020). Understanding adult social stances during a children's museum visit. In Gresalfi, M. and Horn, I. S. (Eds.*), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 1* (pp. 609-612). Nashville, Tennessee: International Society of the Learning Sciences.

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Cox, M. (2021, April). *Making sense of the chaos: New methods for activity tracking in a children's museum.* Bi-annual Educational Psychology & Learning Sciences Research Symposium, Iowa City, IA.

Cox, M., & DeVane, B. (2022). *Making sense of the chaos: New methods for activity tracking in a children's museum.* Presentation at American Education Research Association Annual Meeting.

Missall, K. N., Nanda, S., DeVane, B., Dietmeier, J., *Cox, M.,* & *Courshon, C*. (in preparation). Examining parent-child communication, affect, and collaboration, during multi-user digital tabletop gameplay: Implications for STEM learning. *International Journal of Computer-Supported Collaborative Learning.*