GAMEDESK

LEARNING GEOSCIENCE CONCEPTS THROUGH PLAY & KINESTHETIC TRACKING

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Introduction

The goal of the Geomoto project was to design, build, iterate and assess a series of embodied and simulated geoscience games, exploring the extent to which interactive and kinesthetic experiences could engage students while promoting learning of historically challenging geoscience concepts. In kinesthetic learning, movement and action replace more passive forms, such as reading and lecture based instruction.

We sought to understand how embodied learning, simulations, and game mechanics could be utilized to teach challenging 6th to 9th grade geoscience topics. We therefore explored how sound, music, kinesthetic learning, and storytelling could become effective features of the GeoScience games we were developing. Narrative structure, explicit goals and rules, consistent indications of progress, intuitive ramping structures (progression of difficulty) and elegant scaffolding systems (building upon learned content) were all to play a role in the creation of a natural progression of understanding for each geological system and related phenomenon. In kinesthetic learning, movement and action replaced more passive forms of learning. The project was developed by the GameDesk Institute, in partnership with Bill Nye the Science Guy, LucasArts, The National Academies of Science, and Cal-Tech, and was supported by The National Science Foundation, The Science and Entertainment Exchange, and The Betty Moore Foundation.

We proposed that through movement and playfully orchestrated "trial and error" visualized interactions, students could experiment with their memory, instinct, and reasoning skills, while learning from the impact of the movement-based choices they make. In such a design approach we hypothesized that an integral relationship would exist between the instructional content and motivational content, whereby content knowledge would be essential for progressing through the game (i.e., forming the Earth; moving tectonic plates; forming mountains, island chains, and volcanoes). We hypothesizes that in such an approach, consistent on-task learning and deeper experiential, integrated learning would result in higher percentages of comprehension and retention.

We selected geoscience because it is traditionally challenging for students to conceptualize, and understand. For example, geological events take place on a huge scale and often through extremely long periods of time. The magnitudes of these scales are difficult for students to grasp. Game simulation can offer a dynamic model for geological phenomena, allowing one to view reality in ways that are not possible in everyday human experience. This offers students the ability to manipulate or modify parameters with regard to these types of geological phenomena. For example, enabling students to move through geographical and temporal spaces by zooming in and out, and by accelerating and decelerating time, one can see the effects of phenomenon such as planetary accretion, orbital patterns, and continental drift. Furthermore, much of what happens with the tectonic plate movement happens underground and below the sea. Games and simulation can help make the subterranean earth visible (e.g., shifts in the mantle directly affect observable phenomenon on the earth's surface). Simulations also supports students in conceptualizing the earth as a fluid, multilayered, complex and interrelated dynamic system rather than a static, homogenous object.

Our initial hypothesis was also that students would be highly motivated to learn about historically difficult concepts if they were situated within embodied, movement-based learning environments. In such environments, student would interact and conceptually "attune" with the content by leveraging kinesthetic motion and a directionality that linked body, hand, or gesture-based movements with specific geologic process and concepts. Gameplay, movement, and simulation would be brought together to provide an intuitive and self-evident understanding of the earth's system over time.




In this paper, we detail how GameDesk, from ideation to implementation, explored these different approaches. We offer insights into our Evidence Centered Design process and reveal how we worked with content experts to inform iterated prototypes for teacher and student testing. We also share our evaluation data to document the resulting game designs efficacy to impact student learning and attitudes.

Overview of Four Explorations:

Based off the goals of the project, GameDesk created four games, including:

- A field ***Planetary Accretion*** game where students learn the principles of accretion.
- A ***Layers of the Earth*** game using the SMALLab embodied learning technology that covers layers of the Earth and the Earth's surface.
- A ***Pangean*** game using the Leap Motion Controller that covers continental drift across the Earth's surface.
- A ***Geomoto*** game using the Leap Motion Controller that covers plate tectonics, earthquakes, Earth's surface, and land formation.

Each approach enables a specific set of assessment opportunities, and the rich data generated by these opportunities each supported specific claims regarding both directly observable and inferred aspects of students' learning and development.

Development Phases

Phase 1: Expert Roundtables

Content Domain Analysis, Creative Narratives, and Learning Outcome Extraction

Interactive learning development demands the integration of a broad range of expertise. It requires careful and intentional collaboration to blend insights from teachers, content experts, engineers, game designers, learning scientists, industry creatives, and education researchers. Game designers and academic officers from Gamedesk collaborated with Bill Nye the Science Guy, Professor James Lawford Anderson, designers at LucasArts, content expertise from CalTech, and teachers throughout Los Angeles to collectively participate in a domain analysis process that thoroughly documented all core definitions, concepts, processes and historical teaching approaches associated with the target learning standards in the field of planetary science and geoscience.

The resulting domain analysis, a method that determines and explores related concepts, properties, and abstractions of a given field, identified nine possible topics for the game; namely, 1) continental drift, 2) layers of the earth, 3) Geomoto, 4) earthquakes, 5) earth's surface, 6) energy in the earth's system, 7) volcano creation, 8) scientific inquiry, and 9) the formation of the planets. For each topic, we identified learning outcomes, extracted core concepts, brainstormed game mechanics linked to the learning outcomes, and storyboarded how these concepts could be visualized most effectively.

The first phase included storyteller roundtables where scientists translated difficult scientific topics into digestible and entertaining narratives. Bill Nye the Science Guy and Professor James Lawford Anderson helped explain the eight topics in terms that all team members could easily understand, for early knowledge extraction. We have found that working with entertaining scientists, beloved professors, and popular teachers accelerated this process given their honed ability to translate complex ideas into simple and engaging forms. The team also captured and noted how these storytellers use words, images, metaphors, drama, and humor to accurately convey fundamental concepts. For a second round of deeper extraction, the storyteller scientists collaborated with more domain focused Cal-Tech Scientists and together explored each conceptual stage of planetary formation. The Gamedesk team then took those narratives and broke down each major unified concept or system into a single learning level design.

Phase 2: Creative Domain Narratives to Game Mechanic Mapping

Gamedesk rapidly prototyped a series of single game mechanics that matched individual concepts and learning outcomes. Each mechanic was subsequently evaluated for playability, fun factor,and fidelity with respect to its effectiveness regarding the related learning outcome. How each mechanic lent itself to a larger game idea and the larger conceptual domain of learning was then also assessed. We then mapped each game module to National Science and California State Educational Standards for 6th through 9th grade Earth Science and Planetary Science courses, making it appropriate and ideal for use in the classroom. Furthermore, a major design goal was to create patterns of interaction and gameplay that mimic the scientific processes that players are studying. As a result, the actual play and system interaction intentionally reinforces the learning goals for the module.

The team examined the affordances of gameplay, creative narratives, and embodied approaches that mapped well to the target conceptual and procedural learning outcomes. Questions that drove this phase include: What kinds of visualizations best capture and communicate the geoscientific concepts of interest? What game and emergent technological features can map to each scientific concept, such as speeding up time, making patterns of accretion more evident, or the linking of hand gestures to plate movement? What kinds of human motion might reinforce a certain concept? For instance, the motion of shaking a rope could capture the relation between wavelength and frequency. Additionally, a parallel goal was to fully explore the domain of geoscience and how it has been taught to students in the past, following the thorough research of concepts, processes, and pedagogical approaches across the domain. This process identified what essential topics in geoscience we wanted to cover (or not cover) and allowed us to set boundaries around the games we were creating, giving us a clearer academic and creative vision for the rest of the project.

In parallel to this process, the GameDesk team also worked with designers and storytellers from LucasArts to develop game ideas, stories, and gameplays narratives that can support the larger concepts. We determined what stories made it fun, relevant, beautiful to experience, and involving. The design was then reviewed with the scientists to ensure that content narratives accuracy has been retained in the design process. Gameplay concepts to concept art was often reviewed and commented on by content experts. As the project moved into Large Scale Development Phase this process continued to be conducted by a full time curricular team that checked for correct terms, illustrations, and processes.

After conducting domain analysis, and investigating modalities, we also experimented with developing large-scale conceptual idea that encompassed a super game that spanned from accretion (creation of the universe) to the layers of the earth. However, it was apparent that to cover such a wide span of topics, the game design would have to be universal to multiple diverse concepts and process and was beyond our scope and budget. This design also minimized player interaction and the multitudes of modalities that we could explore. It reinforced our earlier hypothesis that it would require several modalities to teach geoscience concepts, and that some modalities would be better at teaching specific concepts.

Phase 3: Technology Mapping

In parallel to the content domain analysis, we investigated various technologies and approaches, such as digital simulators and motion tracking devices, and outdoor field games that could be adopted to teach the topics we explored in phase one. We explored new emergent technologies (*Smallab, Leap Motion Controller*) and ones that have existed (field games, movement games, Wii, and Kinect). We researched and identified these various modalities and began mapping game mechanics to the learning outcomes and consider how they would be represented in the different modalities. From here, we determined the affordances of each modality and made informed decisions on which ones to adopt for the creation of our games.

The four modalities that were chosen for full prototyping were: 1) the physics-based space simulator, 2) a no-tech embodied outdoor simulation approach, 3) a full body tracking learning technology, *SMALLab*, and 4) the *Leap Motion Controller*, a device that accurately tracks human hands and fingers.

Each approach allowed for a different experience, environment, affordances to learning, and feasibility of scale. For example, during this phase, we discovered that the *Leap* was an ideal technology for 'traditional classroom' modules. Its small size and low per unit cost made it feasible for a 1:1 device to student ratio. Compared to other motion tracking devices we researched, such as the *Kinect*, the *Leap* had a smaller field of capture which limited the amount of interference from other people. Moreover, its ability to capture a high degree of hand articulation and digital movement were conducive to the kinesthetic game mechanics that we mapped to the learning outcomes (e.g., grabbing, pulling apart and together). Further discussion with the manufacturers of *Leap* were also fruitful as we learned that the devices can and may be embedded into laptops and desktops easily, possibly making them a ubiquitous technology in classrooms.

Phase 4: Large scale Prototype Design and Development

After conducting content domain analysis, technology analysis, and investigating design modalities, we began developing large-scale conceptual prototypes. We looked at different approaches to determine which technologies and interactive designs aligned to the type of learning intended for the experience. This phase entailed determining what will make the larger game and simulation experiences content-relevant, kinesthetically well matched, and consistently engaging. With respect to game mechanics, we integrated learning mechanics and game designs from the earlier phases into a set of goals and obstacles that could clearly express a geoscience concept and/or require a player to learn or apply the concept. Of these developed ideas we examined which kinds of mechanics a player could enact that would provide clear *evidence of learning*. Finally, we considered the ways that traditional geo and planetary science learning outcomes were typically assessed and integrated game actions that were likely to transfer to successful performance on more traditional assessments. For example, Geomoto involves a series of directional movements associated to plate phenomenon. We designed a 3D gesture-based game whereby hand movement was linked to plate movement and their resulting phenomena (volcanoes, earthquakes, etc.)

Phase 5: Science Content Revisions

A Content team and experts ensured that accuracy was retained throughout the design process. These reviews consisted of a set of "checkpoints" including considerations such as: What specific elements of your designed game play lead best to the desired learning outcomes? How accurate are your 3D visualizations to the conceptual phenomenon. Is the process you're showing, the gameplay your listing, or the visualization accurately conveying the science? What kinds of data will the game generate that can be used to make assessment inferences? Our in-house curriculum team provided feedback to the design, ensuring that key terms were being used appropriately and game mechanics were intrinsically integrated into the content. Moreover, we took into consideration the feasibility of the modalities with respect to how easily they can be adopted in the classroom. The core-content team and executive leadership reviewed the prototypes to ensure that the learning outcomes we identified in the previous phases were being met, and that the overall vision of the project was intact. This review informed the next full development phase as more user interaction was refined and full game sequences were developed.

Phase 6: Full Game Development

After identifying different modalities in phase 3, we designed large scale prototypes for each of them. This series of learning experiences developed comprised of (1) full-body large-group movement interactions in mediated outdoor environments with no technology support [*Planetary Accretion game]*, (2) a full body tracking floor projected environment that leverages 1:1 ratio between physical manipulatives and floor projected digital science concepts and processes [*Smallab - Layers of the Earth*], and (3) gesture-hand movement based 3D games that leverage hand movement tracking with game mechanics to introduce and reinforce essential geoscience concepts [*Geomoto and Pangean*].

Open Field/Full Body Game
Stages of Planetary of Accretion

Description of Design

The embodied field game was designed as a full-body simulation in which students go onto an open field or large room and model, using their own bodies, how dust particles in space formed into chondrules, asteroids, and planets. The accumulation of matter in space is the reason that planets, comets, the asteroid belt, and everything else exists in the universe. This accumulation relied on chance encounters governed by simple physical properties and rules. The games learning goals were to focus on how students can develop an intuition for how the planets and other objects in the solar system form and learn the various stages of planetary accretion. We began remixing and extending a concept from the NASA Discovery Program wherein participants role-play as particles in space.

in our tested scenario, students “explode” onto the field, then following a set of game rules, they begin to move towards each other based on how close they are (proximity) and the size of each group. Students follow these "rules" and inspect outcomes to see if rules lead to results consistent with observation. They then adapt rules to get better results. This exploration seeked to examine whether students could learn and understand through play the various stages of astronomical object growth, including dust particles, chondrules, meteoroids, asteroids, planetesimals to planets. It also posed that students would attune through movement and group interlocking that matter attracts matter and the amount of attraction depends directly on the objects' masses and indirectly on the distance between objects.

Go to a large open space where all of the participants can see and hear each other but still have a lot of room to run around. All students should pick a random starting point in the space. The facilitator explains that everyone is a particle of dust in the universe and that they will be forming a solar system by following just a few simple rules:

- You must move towards closer objects.
- You must move towards larger objects.
- You must always move around a center point.
- When you are close enough to someone else so your hands can reach each other, you are to link hands (or arms) and then move as a unit, following the same rules as before

As soon as some students have formed into larger groups, the labels change according to the following breakdown:

Space Structure	Group Size
Dust Particle	1
Chondrule	2
Meteoroid	3-10
Asteroid	11-14
Planetesimal	15-17
Planet	18+

The low-tech design of the game allowed us to perform many large scale classroom sized playthroughs and repeat and augment those playthroughs in real-time based on student response. We looked for retention of major terms, explanation of major processes and concepts, and how they responded in the movement based choices they made in every playthrough.


Full Body Motion Tracking Game - Layers of Earth

Description of Design

The Layers of the Earth Game was designed as cooperative floor game that teaches differentiation, layer materials, and density using a slide puzzle-style game mechanic. Up to three students can play simultaneously. Each player controls a specific material: core material (iron), mantle silicate, and crust silicate, across the floor projected environment using their bodies and arm motions to move the materials. The movement of material is constrained by the natural properties of that material. Iron, the most dense, can move sideways and downward. Mantle silicate can move up, down, left, and right in its own zone (but not into the crust or the core). Crust material can move up or sideways. Students must cooperate to solve the puzzle by shifting the positions of their material and accommodating the movement of the other two players' materials. The goal of the game is to sort the materials into the appropriate layers of the earth.

Students are facilitated to explain what they observed, what they think those observations mean, and other things they wondered during the exploration phase. Students are encouraged to make hypotheses on what they saw and what those phenomena may mean in the context of geoscience. Questions from the teacher guide the discussions and facilitate the creation of hypotheses. Examples of these questions are: (a) Why do you think this particular material can only go down? (b) How does this relate to the natural properties of the materials? What properties of matter might explain these phenomena?

Students then work together in groups of three and collaborate to achieve the game goals. In many situations, they need to clear the path for one another to achieve their goals (i.e. cooperation is not optional but required to succeed in the game). Student trios talk amongst themselves, and they also talk to other trios, offering advice as to the fastest ways of accomplishing their goals. Since the rules of the games align with the natural properties of the materials, students learn these foundational concepts as they play.

Students and the teacher discuss the connections between what they learned while playing and how it relates to the layers of the earth. We observed that students would play and create meaning around the materials, the concept of density, and the idea that more dense fluids sink and less dense fluids float through the process called differentiation. During the “final discussion” phases students created meaning and predicted that differentiated objects must at one time have been in a fluid state, and that differentiated solar system objects such as the Earth, must have been in a fluid state at some point of their developments. Students then explained that more dense fluids sink and less dense fluids float through the process called differentiation.

Pangean - Leap Embodied Hand Movement Game

We then decided to explore and experiment with the *Leap Motion Controller* based on its practicality in a classroom (e.g., the device's small physical size, its highly accurate motion capture system, and low per unit cost). At this point, we prototyped a number of simulations around fluid dynamics (e.g., lava cooling and changing states as the user moves their hand higher).

Leap proved to be ideal technology for our modules. Its' size and low per unit cost made it feasible for a 1:1 device to student ratio. Compared to other motion tracking devices we researched, such as the *Kinect*, the *Leap* had a smaller field of capture which limited the amount of interference from other students in a classroom environment. Moreover, its ability to capture a high degree of hand articulation and digital movement were conducive to kinesthetic game mechanics that we mapped to learning outcomes we had previously designed for a plate tectonics game (e.g., grabbing, pulling apart and together). Future versions of the devices are planned to embed into laptops and desktops, possibly making them a ubiquitous technology in classrooms.

With the *Leap Motion*, since the time to create prototypes for that device would take longer, we decided to create technical prototypes around systems/concepts we knew we wanted to explore (e.g., plate tectonics), in UNITY.

Description of Design

We designed *Pangean* as a didactic puzzle game, intended to be used to introduce the concept of continental drift without prior knowledge of the concept. In this game, the player is a member of the United Colonies, looking for a new planet to colonize. Armed with their own scouting ship, hologram computer, and hyperjump drive, they'll jump from one planet to another, piecing together the continents to see how they've shifted over the past few hundred million years. Three key forms of evidence are introduced as students level up in the game. In the initial levels, the only information available to students is the shape of the continents. Using translation and rotation tools, they move the continents back to their original positions. In subsequent levels, the shape information becomes inadequate to solve the puzzle, and an additional tool is introduced--a “probe”--that reveals fossils in the continents. With this additional information, the puzzles become solvable. The third form of evidence students learn to use is the shape of the continental shelf, which students can see by scanning with sonar. Each level increases in complexity, with the final level being to return present-day Earth to its Pangea state. To do so, students must make use of all three kinds of evidence--shape, fossils, and continental shelves--as well as translation and rotation.

Teacher facilitation questions included the following:

- What do you first look for to help you correctly connect one continent to another?
- Why do you think the continents can be connected with each other?
- How did you use fossil remains to help you connect continents up?
- Why do you think similar fossils are found in different continents now?
- What are underwater shelves? How did they help you connect the continents to each other?
- How did you find the shapes of the underwater shelves? Do you think technology played an important part in how you found them?

The game was designed to allow students to use reverse engineering to understand geological models. They work from the present to determine what the past looked like. The design looked to promote pattern recognition as clues to relationships as the visualizations and scaffolding of techniques were proposed to illicit players to examine and use patterns to solve problems. Leveraging visual clues, they are put into a position to use evidence such fossil evidence, provide support for the theory of continental drift.

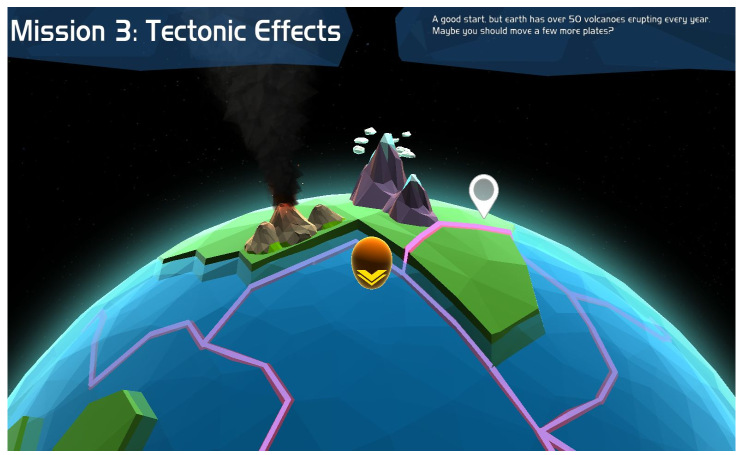
Geomoto - Leap Tracked hand movement gesture game

Description of Design

Geomoto evolved what we learned from developing with the *Leap controller* on *Pangean* and the game design features from *Layers of the Earth* and *Accretion* and looked to develop an experience where players kinesthetically have a direct relationship to geo-concepts. This direct movement correlation to play was to create geographic features by pulling, smashing, and grinding tectonic plates together. Using the Leap, players navigate around a planet devoid of geographic features. Players zoom into the plate boundaries and experience the motion of the plates through the movement of their hands. When they zoom back out, the features they create a decorated globe, allowing them to simultaneously see the earth as a system while giving them a sense of ownership over their planet.

Throughout the game, challenges consistently put the learner in a position to move their hands across land and sea surfaces and observe how plate tectonics create surface features of the Earth, such as volcanoes, folded mountains, rift valleys, and sea-floor spreading. Players make specific observations about the structures created from plate collisions and then act on those observations with hand movements as they go. These interactions allow students to observe the functions and effects of convergent, divergent, and transform plate boundaries.

Visualizations in the game also allow players to also observe subduction zones, that when earthquakes occur when two faults suddenly slip, and that the magnitude of earthquakes is measured on the Richter scale, and that divergent boundaries allows magma to rise up from the mantle and create new crust.



Some of the learning outcomes proposed by the game design claim to address core curricular questions such as:

- What are plate boundaries? List the different types.
- If you are shown a plate boundary, how would you go about identifying what type it is?
- What type(s) of plate boundaries do you think a volcano can be formed from? How are they formed?
- Why type(s) of plate boundaries does a rift valley indicate? Why?
- What kinds of landforms can a convergence between two continental plates form?
- Why would you create a divergent plate boundary to cause seafloor spreading?
- What are the differences between reverse faults, strike-slip faults and normal faults?
- What do you think causes earthquakes? Why?

Phase 7: Small Group User Testing

Large prototypes were playtested in small, focused pilots with students and teachers to confirm whether the intended learning was happening or not. GameDesk held walk-in playtests gathering both user and observer feedback. We examined the users' ability to gain conceptual understanding from the games, the teacher's ability to understand and facilitate the experience, and offered preliminary tests of our main hypotheses. Individual users would engage with the games, and talk aloud as our lead game designer, Joe France, made written observations. This allowed us to see where users would get stuck, what they liked/didn't like, bugs in the prototypes, and whether or not the geoscience content was intrinsically integrated to the game mechanics. Gathering this data provided us with valuable and quick feedback, making the games more robust, both in gameplay and content, for the next phase. By observing small and large group user testing, we were also able to extract best teaching practices, informing us of the best facilitation methods to produce the intended learning outcomes. All user testing was documented through written observations protocols and via video.

Phase 8: Data Gathering and Analysis

User testing provided key feedback. We learned that the *Smallab - Layers of the Earth* and *Active Accretion Field Game* required proper preparation for accurate facilitation and well-trained facilitators in order to run the games whereas *Pangean* and *Geomoto* required little to no facilitation.

When reflecting on the game in relation to our hypotheses, we determined that we needed to integrate more educational content in a more explicit way. We needed to clearly introduce and reinforce key terms and create better visualizations for the players' actions. We revised several modules so that we would cover fewer concepts that make the remaining concepts more explicit visually and allow players to a deep-dive on those concepts. Changes were made to the to *Pangean* and *Geomoto* to optimize motion capture of hand and finger orientation.

Phase 9: Larger Group Focus-Testing at the PlayMaker school

Games were then tested at the GameDesk's PlayMaker School at New Roads, a middle school, which served as a year-round play-based learning model and research and development site. Here we could see how experiential learning could actually be implemented and used in the classroom with a full class of students and teachers. The *Accretion field game*, *SmallLab Layers of the Earth*, and *Leap Pangean*, and *Leap Geomoto* were tested. The Users were 36 6th grade students and two middle school teachers. Testing was documented via video. This environment allowed us to see how the games would actually be implemented in a school setting with the intended users of the project.

GameDesk held and facilitated several face-to-face PD sessions with the PlayMaker teachers to help prepare and plan for each game. These sessions had several pedagogical objectives:

- To fully understand the topic at hand
- To determine desired learning outcomes
- To identify the main misconceptions students tend to have about this topic
- To role-play the activity among teachers in order to refine design and details of the implementation

- To practice facilitation techniques and core questions to be discussed with students after the activity

The GameDesk team held sessions attended by PlayMaker teachers and discussed possible misconceptions that were presented by these scenarios, and decided the order in which these activities should be presented to students. The GameDesk team proposed some early prototypes/ideas, early enough so that there would be enough time to modify or even omit if the teachers didn't agree with the content or the activity itself. The team followed this model to foster among teachers a sense of ownership and commitment to the activity and the approach used. The approach proved effective as these sessions yielded several rich enhancements and modification that resulted in more engaging and appropriate learning experiences for students than the earlier prototypes GameDesk presented. Collegial collaboration was achieved as GameDesk developed the the final games with input received from PlayMaker teachers and students throughout the year. It was important for us to see the social interaction students had with each other and the teachers in each modality. This informed phase 9, where we made revisions based on misconceptions students still had, the feasibility and merit of each of the modalities, and other gameplay issues that were still present. In this phase, we were also further able to test our main hypotheses at a larger scale.

Phase 10: Final Revisions

Student interview data, observation data, and teacher interviews were analyzed from the larger group focus testing and the project team made revisions to the games. Qualitative data from observers and users were recorded and reviewed by the design/curriculum team. We not only reviewed the content but also the modality of the experiences. Sample reflective questions include: What were students doing in the field game that they weren't doing in any of the other games? What do students' specific hand motions with the *Leap* tell us about their knowledge of the content? Revisions to content and gameplay were made.

Phase 11: Pilot Evaluation

A large-scale evaluation was conducted at seven middle schools in Los Angeles County to test our main hypotheses. Three of our games were tested with 300 students. Evaluation was conducted using a staggered experimental design, with data collected regarding students' STEM knowledge as well as science career aspirations and attitudes. Students completed pretests tapping their conceptual knowledge, STEM attitudes, and topic interest. Participants' situational interest were assessed *in situ* during implementation. All measures were re-administered immediately following the intervention. A third party evaluator conducted a pilot test for the *Active Accretion* field game, *Geomoto*, and *Pangean* across seven different middle schools. *SMALLab Layers of the Earth* was not evaluated because of the amount of time it would take to install the software and properly run them. Pretests were administered to all students who completed them individually. Students played the game for one class period, and completed the posttest immediately after playing the game.The evaluator pulled questions from the California Standards Test, the National Assessment of Educational Progress (NAEP), and the Geoscience Concept Inventory developed and validated by Prof. Julie Libarkin to assess college student geoscience knowledge.

After several rounds of small playtests and game design iterations, we implemented a formal evaluation to see whether students who played the games would experience the targeted changes in knowledge and attitudes. We decided to test each game module as a stand-alone experience, so that we could examine its unique contributions to students' learning. Consequently, different groups of students were recruited to evaluate each game module so there would be no confounding of learning across modules .We conducted a pre-post quasi-experimental study. For each game, different groups of students participated.The tests included challenging questions with a strong emphasis on conceptual understanding, such that mere exposure to the questions would be unlikely to result in improved responses unless real learning had indeed occurred. Although quasi experimental designs do not enable strong causal conclusions, they do provide helpful information regarding the promise of the games to foster learning, and provide solid justification for continued iteration of the games, as well as the investment of time and resources in a more rigorous experimental evaluation.

Pangean . One-hundred ninety students provided complete pre-post data sets for the Pangean measure. The Pangean test comprised six open-ended knowledge questions, five selected-response items on geology interest and career awareness, and one open-ended question about the geoscientist career. There were also seven ratings items for students to rate the game experience.

A one-sample t-test, using a "0" test value, was applied to determine whether students made statistically significant gains on the open-ended response items. Results for each of the open-response questions were statistically significant, with averages ranging from 0.03 to .23 and p-values less than .004. The total average gain across the six questions was 0.55, indicating modest knowledge gains. For all five geoscience and geoscience career items, paired-sample t-tests were employed. Results indicate that students' post-test ratings were significantly higher ($p<.001$) than their pre-test ratings. These results suggest that playing the Pangean game had at least a short-term positive effect on students' interest in geoscience as a topic and a career option. Finally, students' post-test ratings of the game itself were analyzed using one-sample t-tests, with a test value set at the scale midpoint (e.g., the neutral point on the scale). Students' responses for all seven game rating items were statistically higher than the "neutral" rating, all with p-values less than .001.

Geomoto. The Geomoto test included three open response items, and either 8 or 15 selected-response items. The longer version was administered on the first day, when the class period was long enough to accommodate administration of a longer test. The second day we administered the short version with 8 selected-response items. Forty-two students participated on Day 1, and 87 on Day 2. On both days, t-test results showed a statistically significant gain from pre to post test ($p< .008$; $p<.001$). On the three open-response items, significant gains were found on students' explanations for what causes volcanoes and what causes earthquakes. As found for the Pangean game, students' game ratings were significantly higher than the neutral point of the scale on all seven items ($p<.001$).

Field Accretion Game. One-hundred thirty three students participated in the field accretion game trial. The test consisted of two open-ended questions ("Briefly explain the process of accretion."; "Give a simple explanation for how the solar system formed."), and eight selected-response items. Paired-sample t-tests showed that students' total scores on the selected-response items increased significantly from pre- to post-test ($p<.001$), and gain scores compared to a test value of zero using one-sample t-tests showed statistically significant gain scores for each of the two open-response items ($p<.001$). Finally, for this game as well, students' game ratings on all seven items fell statistically above the neutral point of the scale ($p<.001$).

Discussion and Conclusions

The evaluations for all three of the geoscience modules showed significant knowledge gains from pre to post. The student improvements from pre to post on these tests ranged from an average of 5% all the way up to an average of 25%. Results for the field accretion game showed improvements of 25%. When students played the Geomoto game, they showed improvements of over 11% from pre to post. For the Pangean game, we saw improvements up to 25%. Results from this evaluation study suggest that the geoscience games are both engaging and educational.

In exploring the use of *Leap Motion Controller and the Smallab motion capture environment*, GameDesk has opened up rich possibilities for the use of such devices to help students understand complex Earth and Science topics as well as other other content areas. The games allowed GameDesk to explore possibilities of using games that have been developed for more mature audiences, and adapting them to a younger audience. The way we did it in this particular case was through the creation of scenarios that limited the amount of data, interactivity, topics and even sections of the game. By creating these scenarios, we focused our students in on specific topics which allowed us to achieve the learning goals. We suggest that we can extrapolate from this experience to other games since there are lots of games that might be too complex for school children of certain ages, but can be made appropriate for their ages with a few modifications.

The use of *no-tech embodied learning activities* like the field-game *Active Accretion* demonstrated that using the whole body as a way to represent either parts or aspects of a topic can help the learner better understand the topic, better comprehend relationships, and better remember it. We hold that no-tech embodied experiences can be used in many areas of knowledge.

We hope that this work will encourage the use of movement and directionality based curriculum and games and motion capture technologies such as the *Leap Motion Controller*. We hope this paper can inspire and illustrate a model on how embodied learning experiences can be used in schools to teach various topics (not only Earth and Space science topics, and not only topics that are traditionally thought of as conducive to using this approach).

Phase 12: Curriculum Development & Media Production

Data from the testing showed the effects of the module on students' Geoscience learning and attitudes. The curriculum team extracted best practices from pilot implementation and user feedback to develop teacher facilitation curriculum and assessment supports around all games. Based off pilot test results, user feedback, and recorded footage, GameDesk developed curricula/lesson plans for the *Accretion field game*, *Layers of the Earth*, *Pangean* , and *Geomoto* that incorporated best teaching practices from our curriculum team and our network of teachers. Each lesson plan consists of a 1) general description of the experience, 2) steps of the interactive experience, 3) its relation to learning, and 4) list of the learning outcomes. We also realized that the breadth of this project could not be fully articulated with just the games and a few text documents; we wanted to tell a visual story of the project about how we did what we did and why. We generated tutorial videos for the games and a video that showed the pedagogical approaches that guided the development of the geoscience games.

NOTE: The full curriculum links are attached to this paper, and we've provided links to videos that detail out each section.

Phase 13: Dissemination and Commercialization

The games and curriculum were packaged for national dissemination and distributed on GameDesk's website, Educade.org. Geomoto and Pangean were considered to have the most potential to scale to schools and homes and had the most potential to port to other platforms. GameDesk decided to invest in the conversion and refinement of those titles to IOS and Android.

Links to Games and Content

Games to Download

The **Geomoto** and **Pangean** games are available now on IOS and Android tablets. Downloads are available at the GameDesk website: http://gamedesk.org/products.org

Games can be also be downloaded at the following stores:

Geomoto for Android   Pangean for Android

Geomoto for IOS   Pangean for IOS

Leap Games can be downloaded at
http://gamedesk.org/project/geomoto/

Educational aids or Curricula

GameDesk also developed curricula/lesson plans for each of the games developed. This includes each of the *Active Accretion* field game, *Layers of the Earth*, *Pangean* , and *Geomoto* where we incorporated best teaching practices from our curriculum team and network of experienced teachers.

SMALLab Layers of the Earth Lesson plan:

http://www.educade.org/lesson_plans/53ebe25639c6ebfba4000001

Active Accretion Field Game Teaching Tool Page:
http://www.educade.org/teaching_tools/active-accretion

Geomoto & Pangean Teaching Tool Page:
http://www.educade.org/teaching_tools/geoscience-continental-drift-and-plate-tectonics

Geomoto Lesson Plan:
http://www.educade.org/lesson_plans/plate-tectonics

Pangean Lesson Plan:
http://www.educade.org/lesson_plans/continental-drift

Videos

Project Video: We created a video that details the goals of the project and summarizes our design process and findings from pilot implementation.
The video can be found here: https://vimeo.com/141112683

User Testing Videos

Layers of the Earth: http://vimeo.com/97530164
Pangean : http://vimeo.com/97526912
Geomoto: http://vimeo.com/97527436
Active Accretion Field Game/*Layers of the Earth*: http://vimeo.com/87731892

Video lesson plan tutorials for *Geomoto* and *Pangean*:

Pangean tutorial video:http://vimeo.com/98674900
Geomoto tutorial video: http://vimeo.com/98674901

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