Math Snacks: Addressing Gaps in Conceptual Mathematics Understanding with Innovative Media

Project Description

Over the last 10 years, researchers, mathematicians, and mathematics educators at New Mexico State University's Institute for Mathematics and Science Education have developed a successful partnership with school districts in which they have built capacity for achievement in mathematics and science for all students. The model includes partnerships with districts, which provide leadership and professional development for their teachers, and share costs with the university project. The Institute also has several NSF-funded projects in mathematics, science, and technology, NASA funding, and funding from over 16 foundations that support outreach and research in STEM education. The proposed *Math Snacks* project team would develop educational media to address gaps in conceptual understanding. Nineteen partner districts have signed formal memorandums of agreements to collaborate with the institute’s Mathematically-Connected Communities initiative (MC2). The gaps in conceptual understanding have been identified through research on this project (and correlate with national data), and research on the use of the materials will be conducted in these 19 districts.

In spite of gains in mathematics learning in the United States (NAEP, 2007; TIMMS, 2007), successful mathematics progress for students in multiple reform efforts (Impact Report, 2008), and the promise of these systemic efforts, there remain significant student weaknesses in mathematics, particularly in those areas of the K-8 curriculum that are intended to prepare students for Algebra (*Adding it Up*, 2001; National Mathematics Advisory Council, 2008).

Recently, in the process of evaluating successful increases in standardized test scores for MC2 districts on the NM Standards-Based Assessment (SBA), the project evaluators noticed that students in grades 5-8 in one district had remarkably consistent areas of weaknesses in core mathematics areas. Careful analysis of student achievement in the successful MC2 project revealed this unexpected pattern, and further analysis of weak areas for students in additional state districts identified many of the same areas of weaknesses. An analysis of 5th and 6th grade scores in another state confirmed similar areas of mathematical weakness, particularly in estimation, understanding number systems and operations, use of positive and negative rational numbers, measurement and geometry. These findings support the current calls for mathematics reform from the U.S. National Advisory Council (2008), which emphasize the need to start at the beginning, when investing in mathematics education--to expand work on number and operations; fractions, decimals and other numerical representations; and geometry and measurement in order to better prepare students for secondary mathematics. These student conceptual gaps in 5-8 mathematics cause problems for students as they move through school. By high school, achievement scores drop dramatically and the gap in test scores between mainstream and culturally and linguistically diverse students continues to be large, showing differences of as much as 20-30 points, not only in New Mexico, but also nationally (NAEP, 2007).

Goals and Purposes

Over the last three years, educators from the institute have been working with developers at NMSU’s Learning Games Lab to create innovative media products for middle-school students in what teachers and researchers had reported to be areas of difficulty for students. This work resulted, in part, in the *Math Snacks* prototypes. The proposed project will expand previous work to address mathematics learning relevant to DR-K12 Program Challenge 2: *How can all students be assured the opportunity to learn significant STEM content?* Through developing educational media for teachers to use in teaching mathematical concepts, as well as instructional guides, *Math Snacks* also addresses DR-K12 Program Challenge 3: *How can the ability of teachers to provide STEM education be enhanced*? The overarching research question in this proposal is: **In what ways can innovative media be used to fill conceptual gaps in middle grades mathematics**?

The **goal** of this project is to **create and evaluate effectiveness of innovative animations and games** specifically designed to:

1. Increase students' conceptual understanding in areas of weakness in mathematics concepts and processes as documented by summative assessments, such as teacher tests and the New Mexico Standards' Based Assessment.
2. Increase students' math process skills with a focus on capabilities to think and talk mathematically, as demonstrated by qualitative interviews, "video closet" testimonials, and student written work at the end of modules.

Developed product will include:

1. Animations and games designed for use by middle school learners in class, during extended learning periods, or at home.
2. Companion print materials as needed to assist learners in applying conceptual understanding to learning.
3. Short video clips documenting best practices by exemplary teachers using the developed materials with students, setting up the learning materials, and reviewing materials during class discussion. Teachers, students and parents could all benefit from the video clips.

Research will reveal:

1. Which students benefit the greatest from developed tools.
2. Whether these media pieces can be helpful when students are in districts that are not participating in systematic math reform.
3. Value of expansion of developed materials to larger and more diverse audiences.

Framework for Development

Addressing Gaps as Identified in Existing Evaluations

New Mexico's Standards-Based Assessment (*NM*SBA) has been shown to correlate well with the NAEP national assessment (Aligning mathematics assessment standards, 2008). The test is given yearly to all students in grades 3 through 8, and again in 11th grade. Fifty percent of the points on this test are reserved for short-answer or open-ended questions. In other words, students must write about their understanding of the mathematics they are doing, draw or interpret tables or graphs, or explain their thinking in answering a problem. In every district in the state, students score lower on the half of the test that includes open-ended items than they do on the multiple-choice section of the test. While students can generally use procedures correctly, they don't demonstrate an understanding of the reasons for doing them. In additional their lack of understanding of the reasonableness of an answer, based on estimation can lead students to perform incorrect computations.

An analysis of over 11,000 student scores in 6^{th}-8^{th} grade in high-need NM districts partnering with MC2 showed consistent areas of weaknesses. In addition to receiving lower scores with the open-ended questions, students had trouble with multiple-choice questions demonstrating understanding (as opposed to just choosing a numerical answer) (Korn &Wiburg, 2008). For example, while students can do measurement, they don't score as well in the section on understanding measurement. In sum, student scores were weak in demonstrating an understanding of number systems and operations, fractions and decimals, areas of geometry, (in particular: differentiating between area, perimeter, and volume); and moving between numerical, tabular, and graphical data describing linear relationships.

STEM Content & Learning Goals

This project addresses middle grades mathematics learning with a focus on basic conceptual understandings of mathematics that are a foundation for further advanced learning. Research supports fundamental mathematics education in order to improve student learning in mathematics, a critical skill needed for students to take advanced courses in the STEM field and eventually become knowledgeable citizens and workers in the 21st century. The National Research Council (Adding it Up, 2001) suggests that the study of algebra is based on students' understanding of number, number operations, number systems (numbers, integers, rational and irrational), number patterns, and the application of numbers to a wide variety of shapes and objects through measurement and geometry. To a student, different numbers systems can seem arbitrary and unrelated. Rational and irrational numbers are harder to visualize than whole numbers, yet all these numbers can be related visually with a representational tool: the number line. This conceptual tool allows a student to interpret whole numbers, negative numbers, fractions, and irrational numbers as part of a single number system, and provides a link between arithmetic and geometry. It is the focus of one of the pilot animations developed in the *Math Snacks* project and deserves further development.

One of the reasons mid-school students lack a conceptual understanding of mathematics may be the relatively undefined and unstructured U.S. curriculum, poor assessments, and the low level of mathematics knowledge required for teachers. As Ginsburg, Leinwand, Anstrom, and Pollock, (2005) suggest in a book comparing the Singapore and U.S. curricula, the U.S. lacks a centrally identified core of mathematical content which could help focus the country's various curricula and teaching systems. National assessments are not utilized as formative assessments for teaching. These authors state that the U.S. "textbooks emphasize definitions and formulas, not mathematical understanding" (p. ix). The same authors continue, "The Singapore texts are rich with problem-based development in contrast to traditional U.S. texts that rarely get much beyond exposing students to the mechanics of mathematics… the Singapore illustrations also feature a concrete to pictorial to abstract approach. *Many students who have difficulty grasping abstract mathematical concepts would benefit from visual representations of mathematical ideas* (p. xii). Multimedia supports learning by providing additional graphical illustrations (Moreno & Mayer, 2007).

If U.S. students are to be more successful, they must begin with a strong foundation in core mathematics concepts and skills, which, by international standards they presently lack. Singapore, whose students ranked first in the international comparison of student mathematics performance at the 8th grade (TIMMS, 2008), has such a foundation. Other high-scoring countries, such as Japan, also have clear national systems that define what topics are to be covered in depth at each grade level (Takahashi, Watanabe, & Yoshida, 2004). In the U.S. there are current efforts to develop a focus on core understandings at specific grade levels. Two examples are the *Focal Points* proposed by the National Council for Teachers of Mathematics and work at the University of Georgia's MSP project, *Partnership for Reform in Science and Mathematics* (PRISM) to provide such a framework for their state schools. The *Math Snacks* project will provide a key set of topics to be explored and understood within a developmental framework of conceptual understanding that moves from the 6^{th}- 8^{th} grade levels.

Gaps to be Addressed

Students have demonstrated weaknesses in these specific performance objectives as defined in NM mathematics standards. The benchmark number is identified in parentheses.

Number and Operations

Grade 6 — Compute fluently and make reasonable estimates. (#1-C)
- Use estimates to check reasonableness of results and make predictions in situations involving rational numbers.
- Compare and order positive and negative fractions, decimals and mixed numbers and place them on a number line.
- Convert fractions to decimals and percents and use these representations in estimations, computations and applications.
- Interpret and use ratios in different contexts.

Grade 7 — Understand numbers, ways of representing numbers, relationships among numbers, and number systems (#1-A).
- Use properties of the real-number system to explain reasoning and to formulate and solve real-world problems.
- Simplify numerical expressions using order of operations.

Understand the meaning of operations and how they relate to each other (#1B)
- Calculate given percentages of quantities and use them to solve problems.

Algebra

Grade 6 — Use mathematical models to represent and understand quantitative relationships. (#2-C)
- Develop and use mathematical models to represent and justify mathematical relationships found in a variety of situations.
- Create, explain and use mathematical models such as Venn diagrams, equations and inequalities, graphs, tables and charts.

Grade 8 — Understand patterns, relations and functions. (#2-A)
- Move between numerical, tabular and graphical representations of linear relationships.

Geometry

Grade 7 — Apply transformations and use symmetry to analyze mathematical situations. (#3-C)
- Determine how perimeter and area are affected by changes of scale.

Grade 8
- Describe and perform single and multiple transformations that include rotation, reflections, translation and dilation to two-dimensional figures.

Measurement

Grade 6 — Understand measurable attributes of objects, systems and process of measurement. (#4-A)
- Estimate measurement in both U.S. customary and metric units.
- Select and use units of appropriate size and type to measure angles, perimeter, area and capacity in both U.S. customary and metric systems.

Grade 8
- Understand the concept of volume and use the appropriate units in common measuring systems to compute the volume of rectangular solids.

- Use changes in measurement units to perform conversions.

Student Learning Goals

Student learning goals for this project will be selected from student performance objectives of the NM Standards and Benchmarks. Media modules will be developed for each performance objective in which students had a weak performance on the state standardized test. Media content will emphasize connecting text, image, and animation, as well as the learning of mathematics vocabulary.

Learning Mathematics with Technology

A great deal has been learned over the last 20 years about the brain and how people learn (Bransford, Brown, & Cocking, 1999). Learning theory has developed from a simple behaviorist view to a focus on cognitive learning, to, more recently, an understanding of the role of the learners' interactions in social and cultural environments in influencing constructivist learning (Vygotsky, 1980; Wertsch, 1988). Some theorists (Papert, 1996) suggest that learning is always more powerful when students are interacting with some sort of artifact, whether it be an electronic object, a programming environment, or the creation of print media. Norton and Wiburg (2003) in their book, *Teaching with Technology: Designing Opportunities to Learn*, describe how technology use has expanded in relationship to learning, serving first within a behaviorist approach to increase the efficiency of learning and more recently becoming a powerful tool to support constructivist learning. Constructivist learning is based on the belief that learners construct their own concepts as they interact with their environment. Vygotsky and his followers (Wertsch, 1988), suggest students perform best when they are in their zone of proximal development (ZPD), where the work is just challenging enough and new enough to be interesting, but not inaccessible based on the student's previous understandings. This concept of ZPD, guides *Math Snacks* projects, and developers use extensive formative evaluation to identify this zone. When students have trouble understanding an advanced concept, they can move to a reintroduction of an earlier, more foundational concept.

As Gee argues, games and newer electronic learning environments provide opportunities that both engage students and require a demanding kind of "reading and writing" that builds literacy and thinking skills (2004).A recent synthesis of research (Heid and Blume, 2008) describes how technology can be used for the teaching and learning of mathematics. Within this research series, Olive and Lobato (2008) describe how the use of technology aides students in understanding rational number concepts. They present six research studies in which students gained understanding of rational numbers through the use of technologies from virtual manipulatives to videos and game environments. Students were able to understand the concepts of equal parts to whole and the use of multiplicative reasoning when using computer-based environments that allowed them to take apart and rebuild representational pieces of objects. Clements, who has done extensive work with young children and computers, suggests that for children, representational objects on a computer are seen as a manipulative. They find such representational objects as easy to use at an early age as blocks and chips. He and colleagues (Clements, Sarama, Yeilland, & Glass, 2008) describe the use of modified LOGO environments to help students learn geometry. Interactions with media around mathematical topics have the potential to help students fill their conceptual gaps in understanding.

Researchers (Hill, Rowan, & **Ball**,, 2005) have found that teacher mathematics knowledge is positively related to student achievement. Many middle school teachers had very little opportunity to learn deep mathematics in their teacher education programs in the U.S. Unlike teachers in other countries, they have not been required to pass high levels of mathematics as part of teacher preparation, nor do they receive continued professional development in learning mathematics for teaching (Ginsberg, *et. al*, 2008). *Math Snacks* modules allow best practices of a guest expert to virtually come into the classroom in order to share mathematics with the teachers and the students via media.

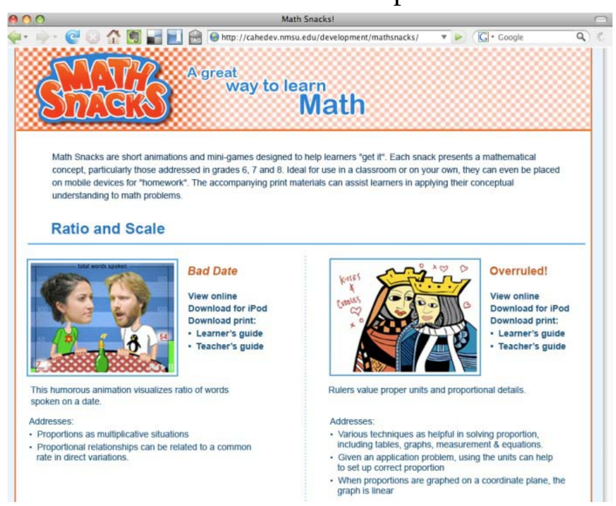
Teacher Needs

For a complete math intervention program to succeed, teacher professional development is essential; However, the goal of *this* project is to address gaps in existing math education efforts, *not to create a new comprehensive curriculum*. The project goal is to create small interventions that can be easily integrated with existing instruction. Ideally, the project guides teachers in using these programs, while taking as little of their professional development time as possible. Teachers need ideas and examples of how to use these animations and mini-games, but cannot be expected to sit through a training or workshop to do so. Short companion videos will be available to teachers in which best practices can be demonstrated. This may include video of a teacher introducing an animation to his class, giving them some questions to think about before watching, or a clip in which a teacher demonstrates math strategies, referring to one of the storylines in the animation to help students remember the concept as it was presented.

Teachers may find it appropriate to use these animations in class with all their students, or more helpful to assign students who are struggling with specific content to view specific animations. Materials will be freely available online and easily accessible by students, teachers, and parents. Materials can also be re-used as many times as necessary.

Math Snacks — Innovative Media to Address Gaps

Recently, team members brought educators, game developers and mathematicians together to develop a series of entertaining mobile technology tools. These tools addressed specific math concepts — such as ratio — that students are not fully understanding, as indicated by classroom observations and state test score analysis. The team is deeply committed to the necessity of working with whole districts in order to improve student mathematical achievement in New Mexico. However it also sees a need to more effectively engage individual students in understanding key concepts in order to develop their mathematical thinking. They believe this task is not well-addressed by providing additional practice with the same look and feel of traditional textbook-based mathematics. Instead of teaching the concept in a "more of the same" manner, team members believe that by approaching the problem from a completely different, engaging, funny and artistic approach, students may suddenly understand a bit of knowledge they have been missing.



Math Snacks prototypes were created to evaluate the potential of short animations and games in helping learners understand concepts before engaging in more formal classroom learning. In a preliminary study carried out by the NMSU Learning Games Lab, 20 mid-school youth were loaned iPods with only educational content on them — they were not allowed to put their own music or games on them. Content included educational videos, such as documentaries, and age-appropriate animations. Researchers found that youth spent approximately 10 minutes a day with the material in the first week. When they found an animation or video they especially enjoyed, they shared it with their peers, and often with their parents as well. This study was the impetus for creating short, entertaining animations. The six resulting pilot animations are popular with students and teachers. Team members created print companion materials to guide teachers and students in applying the conceptual understanding to math skills. Pilot animations and materials are available at http://www.mathsnacks.com.

Pilot Math Snacks Animations • mathsnacks.com

These tools proved popular with teachers in grades 5, 6, 7 & 8 and teachers. We propose development of new, similar math materials using the design process established during the formative research period.

Bad Date
Humorous animation visualizes ratio of words spoken on a date.

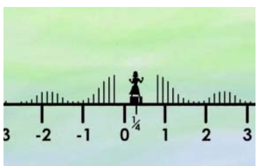
- Proportions as multiplicative situations
- Proportional relationships can be related to a common rate in direct variations.

Overruled!
Rulers value proper units and proportional details.

- Various techniques as helpful in solving proportion, including tables, graphs, measurement & equations.
- Given an application problem, using the units can help to set up correct proportion
- When proportions are graphed on a coordinate plane, the graph is linear

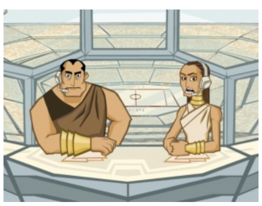
Scale-ella
A crusading superhero clarifies and uses *scale factor*.

- Objects that are scale representations of each other have the same shape but not the same size, & the size difference is related to the scale factor



Number Rights
A passionate activist clarifies equality on a numberline.

- Equality of representations and order on the number line
- Number line as a conceptual organizing tool
- Positive and negative natural, integers, and rational numbers



Atlantian Dodgeball
Ratio errors confuse coach in an epic dodgeball tournament.

- Ratios can represent part-whole or part-part relationships.

Based on their experience developing these prototypes, the team is confident they can create new animations and short games that appeal to the target audience and help learners ‘conceptual understanding of math concepts. In the previous development process, they refined their approach (including the ability to estimate product development time cycles); established a solid working relationship among the game developers, animators, mathematicians and educators; and developed skill in translating the crucial educational objectives to engaging media. The first six products developed are now ready for further testing with teachers in classrooms in order to make them as effective as possible.

Scope

During the 5-year project proposed here, the team will develop approximately 15-20 animations or mini-games. Based on previous development patterns, 20-30 ideas will likely enter into the design process in which rough scripts and testing ideas are developed. Extensive formative evaluation will be used to select out those products promising to be most successful. Before the existing *Math Snacks* animations were finalized, each went through multiple script revisions, as many as 23 working versions in one case. During the design phase for the existing *Math Snacks* modules, several animations and ideas were storyboarded and animated, but were not completed: some were not engaging for the youth, some were deemed inappropriate by the quality assurance committee, another wasn't needed after similar concepts were covered successfully in already existing animations. This storyboarding and prototyping is an important part of the design process.

Each of the completed animations or mini games will include:

- 5-15 minutes "seat time", meaning the final animation or game will be viewable or playable in that amount of time.
- Companion print materials where necessary, giving learners the ability to apply the conceptual understanding in a demonstrated mathematics application. For example, the *Bad Date* print materials encourage learners to script their own conversations and to use ratios to compare the numbers of words spoken by the two parties.
- Video demonstrating best practices for integrating the animation or mini game with classroom learning. For example, one video may demonstrate a skilled teacher leading a classroom with discussion prompts to reflect on what was learned in the video. With this tool, teachers can get ideas on how to best integrate the short animations and games with classroom instruction. Additionally, parents and students can access the videos if they are using the tools outside of a classroom context.

All animations and games will be posted in multiple formats to ensure accessibility from multiple devices. Currently, *Math Snacks* animations are available in a Flash format (accessible via the web and some handheld devices) and QuickTime mp4 format (viewable through iTunes and iPods). As formats evolve over the coming years, *Math Snacks* modules will be updated, giving teachers and students maximum flexibility in how and where they view the animations and play the mini games.

Accessibility of Materials

A top priority for the design team is creating media that are accessible to as many audiences as possible. From a design perspective, the development team applies the guiding principles of Universal Design for Learning (UDL): providing multiple means of representation (visual, auditory and printed text), providing multiple ways of action and expression (such as varied ways to apply their knowledge through discussion or another creative outlet), and providing multiple means of engagement. Many of the animations and mini-games will likely provide redundancy in content covered, so that an individual learner that is not engaged by one may find another of interest. CASTS's UDL principles will guide the design team in their approach to developing content. A Quality Assurance committee will be asked to evaluate the materials at several stages of development for different quality markers, and accessibility will be one of the criterion for their review.

Design Process

NMSU's Learning Games Lab has been refining their development process throughout their 18-year history of educational computer game development. Their approach has similarities to the backward design approach outlined in *Understanding by Design* (UbD) including a focus on what students need to know and an emphasis in helping students uncover ideas through learning; using key design questions to define the expected understanding and designing activities that lead learners to perform expected outcomes. (Wiggins, McTighe, 2005).

Development Team Structure

Notable in NMSU's process is the integration of content specialists, learning experts and stakeholders (usually teachers and learners) with their creative team, throughout the design process. In contrast to many learning experiences that are designed by educators then given to contracted developers who follow the blueprint for design, NMSU's team places all team members at the design table throughout the process, so that *all* members — from mathematician to animator — are involved in asking the guiding questions, reflecting on expected evidence of learning, and brainstorming engaging and meaningful learning experiences. In this way, all members bring their own expertise to share with others. As inevitable changes occur throughout the iterative design process, the development team is well-equipped to think through the changes to find valuable solutions. The whole design process is team-focused and each team member has a different professional background that contributes to the overall success of the games. The design team includes programmers, illustrators, project managers, instructional designers, scriptwriters, game lab consultants to human computer interaction professionals. When everyone at the design table has equal input into the final product, richer products are developed that are more likely to reflect the innovation of design professionals, the pedagogical strength of educators and the content accuracy of mathematicians and scientists.

Developmental Process and Iterative Research

Each project starts out with a set of overall goals and objectives specific to the project. These are often based in state or national standards. For *Math Snacks*, they are the gaps in understanding as outlined previously. The design team discusses these goals and objectives aided by **guiding questions**:

- How is this content currently being taught? Why is that not working?
- What common mistakes do learners make?
- How do we know if the learner fully understands this? What can they do, say or demonstrate?
- What would they do or say if they don't fully understand this?
- What should the learner know, do and understand to be able to learn this content?

These guiding questions are different from the questions issued in formative research in that they guide the development team in preparing their initial designs and are asked before any product is developed. It reflects the team's philosophical approach to development that new materials must do more than simply quiz learners or lecture learners in an entertaining voice.

Throughout this process, the educational objectives are often revised, broken down into sub - objectives, or grouped together. The team does not strive to create one tool per objective, rather, they look at the objectives as a complete group and group appropriate items together. This master educational goal sheet is finalized to serve as a touchstone throughout development and brainstorming. As the team moves through brainstorming, they think of ideas and concepts, but always return to the master educational goal sheet. This process usually takes a couple of days, and extensive notes and video summaries document the ideas in place. During the next concept design phase, members break out into smaller groups or take on individual parts of the design process to produce sketches, animations, and/or working prototypes that will initiate the iterative design phases of the project. Usually, one or two team members take the lead on this, deciding when to share versions with the larger team, and when formative testing is needed. During this process, the team meets weekly to review ideas. The iterative testing phases help to refine the concepts, design and gameplay.

Formative Testing

Another key component of NMSU's design process is the integration of formative testing into product development. Many development teams integrate formative testing by showing working prototypes to audiences and revising the product. However, NMSU integrates formative testing much more frequently, and with more groups, than most other design teams. NMSU's process utilizes learners, teachers and quality assurance experts so that products are reviewed throughout the design process, sometimes even weekly. This allows a much faster iterative process in which, for example, a character can be developed for an animation, and taken to a focus group discussion with youth that day as a pencil sketch before animators spend additional time animating it or developing it into a working prototype. As part of its design process for this *Math Snacks* project, the team will utilize:

1. **Middle-School Youth in the NMSU Learning Games Lab** who are available every day during the summer and at least twice a month during the school year. These youth participate in a variety of review and design activities. NMSU faculty have developed a wide range of review tools, including traditional focus group discussions, one-on-one discussions or two-on-one observations, daily blog prompts and the ever-popular video closet "confessionals". Such access to youth testers ensures that all components (such as characters, level design, story concepts, titles and names) are tested frequently during development and are appealing to the target audience.

2. **Teachers, Classrooms and Learning Experts:** Math educators on the team often take working prototypes of materials into classrooms and ask teachers, with whom they have established relationships, to use and test the products. Through interviews with the teachers and students, as well as observation by faculty, team members can uncover ways in which the tools can better blend with classroom instruction, such as the need for special supplemental materials or 'pause' buttons on an animation. Feedback from teachers on existing *Math Snacks* prototypes was critical in helping the team create companion print materials and make necessary changes for classroom use.
3. **Quality Assurance Committee:** The Wexford Institute will manage a Quality Assurance committee comprised of experts in mathematics, technology, professional development and research. This committee will provide an independent review of the resources, models, and

technologies developed by the project, beginning with review of the research design, methodologies, and execution of each objective. This review process will continue during meetings (face-to-face and virtual) twice each year at times that fit best with the development and research design. Wexford will conduct these meetings, based on a quality review process it has used in previous projects, and insuring the independence of the panel.

Formative research on existing prototypes will address:

- How do the initial prototypes work in middle school classrooms? Do some tools seem to be more effective than others in aiding students to learn mathematics concepts?
- Do specific tools work better for some students than for others?
- How do the products need to be changed to make them more effective?
- How do effective teachers use the materials? What are the best practices for introducing the materials, or integrating them with instruction once they've been used?
- How do successful students interact with the materials?
- Does the quality of math discourse improve as students interact with the *Math Snacks?*
- Do results of formative field testing differ significantly in terms of effectiveness by school, teacher, student characteristics and/or grade level?

Data will be collected through observations, focus group interviews, one-on-one and two-on-one observations, think aloud activities, and video closet testimonials. All qualitative formative data is analyzed using a variety of qualitative methodologies, as appropriate, from simple observer discussions to post-collection for simple character reviews to more in-depth. Focus groups with students as well as interviews are transcribed and coded in order to find consistent themes which provide detailed feedback.

Product Delivery

As the products move into development, versions are posted to an internal website where all team members can review progress on multiple versions and formative testing audiences can access the materials. All scripts are reviewed by the content specialists for specific review at this time as well. The cyclical process of design – review – modify continues until the module is complete. The Quality Assurance committee must approve a version until it is ready for final release. As a module nears completion, companion materials – such as print materials or supportive video clips – are developed and enter a similar, though often shorter, design process.

<table>
<tr><th colspan="6">Timeline</th></tr>
<tr><th></th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th></tr>
<tr><th colspan="6">Development</th></tr>
<tr><td>Wave 1: 5-8 Products</td><td colspan="2">Development and revision</td><td>Delivery</td><td colspan="2">Revision as needed</td></tr>
<tr><td>Wave 2: 5-8 Products</td><td></td><td colspan="2">Development and Revision</td><td>Delivery</td><td>Revision as needed</td></tr>
<tr><td>Wave 3: 4-5 Products</td><td></td><td></td><td colspan="2">Development and Revision</td><td>Delivery</td></tr>
<tr><td>Website</td><td colspan="4">Working prototypes available for download</td><td>Final versions available</td></tr>
<tr><th colspan="6">Formative Testing</th></tr>
<tr><td>Learning Games Lab</td><td colspan="5">Test characters, interface, ideas, with ~ 60 youth throughout year.</td></tr>
</table>

Teachers and Classrooms	Test working prototypes with teachers and students in ~20 classrooms annually.				
Quality Assurance Committee	Review materials twice annually.				
Randomized, Controlled Trials			Wave 1	Wave 2	Wave 3
External Evaluation					
Evaluate progress on goals and objectives	Mid- and end-of-year staff surveys				

Research Questions and Design

The overarching research question in this study is: **In what ways can innovative media be used to fill conceptual gaps in middle grades mathematics**? The project team is interested in designing media to address specific gaps in conceptual understanding for middle grades students. The formative research was described earlier. Once full versions are completed, testing research will begin with randomized control trials.

Randomized Control Trials for Years 3, 4, and 5

The research team will use a study design strongly suggested by NSF (NORC, 2005), a Randomized Control Trial design for projects such as this one that is testing the effectiveness of a product for learning. The hypotheses to be tested, the protocols and instruments used for evaluative purposes and the planned statistical analyses are described below.

Hypotheses, Evaluation Protocol, and Statistical Analysis

Hypothesis 1

Students in experimental classrooms will increase their **conceptual understanding of given mathematical concepts** at a significantly higher level than students in control classrooms as measured on the New Mexico Standards Based Assessment (NMSBA).*

Evaluation Protocol	Statistical Analysis
A. (NMSBA) mathematics results for students in Grades 6, 7, and 8 will be disaggregated and analyzed to determine similarities and differences in the performance of students in experimental classrooms as compared to those in control classrooms. • by overall mathematics proficiency, • by each area originally identified as an area of weakness • by ethnicity, gender, level of English language learning, socio-economic status and enrollment in special education B. Results from post-test for each module will be analyzed to determine level of proficiency demonstrated by each student.	Pre-treatment equivalence will be compared with post-treatment scores by student within treatment and control classrooms. An analysis of variance will be used to compare the performance of students. in experimental and comparison classrooms. A mixed effects linear model will be used to examine differences in treatment means as well as differences in variability.

** NMSBA is administered in spring of each school year: results available September 1 of following school year.*

Hypothesis 2

Students will **retain their understanding of math concepts longer** in experimental than in control classrooms based on year-end scores over time on the NMSBA.

Evaluation Protocol	Statistical Analysis

New Mexico Standards Based Assessment (NMSBA) mathematics results for students in Grades 6, and 7 will be disaggregated and analyzed by the categories listed above for the students. Student scores will be aggregated by type of classroom, experimental or control. Repeated measures of student understanding will also be given 3 times during the one year experimental trial. NM schools give standardized formative assessments during the year. We will use these scores as well as repeat the post-test developed with the modules.	Comparisons of year to year student test scores using an analysis of variance over students 6th and 7th grade years: 3 years of comparisons for 6th graders, 2 years of comparison for 7th graders.

Hypothesis 3	
Students in experimental classrooms will **increase their effective use of math process skills** as measured on open-ended portion of the NMSBA at a significantly higher level than students in control classrooms.	
Evaluation Protocol	**Statistical Analysis**
Changes in the percentage of possible score points students earn on the open-ended portions of the NMSBA will be analyzed using a pre- and post-treatment. Changes in scores for experimental and control classrooms will be compared.	Pre-treatment equivalence will be with post-treatment scores by student within treatment and control classrooms. An analysis of variance will be used to compare the performance of students in experimental and control classrooms on the open-ended items on the test. A mixed effects linear model will be used to examine differences in treatment means as well as differences in variability.

Hypothesis 5	
Teachers who use the multimedia tools with their students in experimental classrooms **will increase their mathematics pedagogical knowledge** at a higher level than teachers in control classrooms**.**	
Evaluation Protocol	**Statistical Analysis**
Participating teachers will be administered the *Numbers and Operations* and the *Geometry* components of the *Mathematical Knowledge for Teachers* test (MKT), annually to determine changes in their mathematics pedagogical knowledge.	We will do a matched-pair item response analysis on the MKT to determine change in mathematical pedagogical knowledge

From the schools currently partnering with the Institutes Math and Science Partnership program, the research team will choose 60 teachers who have agreed to try these materials with their students for a year. Thirty of these teachers will be randomly selected to serve as the experimental group in year one, while thirty of the teachers will serve as a control group. Both groups will do the same pre and post testing, teach similar content, and assist researchers with gathering data. Experimental teachers will use the *Math Snacks* multimedia modules. Student learning will be assessed in several ways including post-tests that are provided with the modules, and standardized short-term and annual assessments given at the school for all students.

In year 4, the 30 comparison teachers will become the experimental teachers and 30 additional teachers will be randomly selected within the same schools to serve as control teachers. One of the advantages of this design is that all of the schools in the population selected will currently be members of one of the state MSP projects and will be receiving monthly professional development opportunities not specifically related to *Math Snacks* materials, whether they are in experimental or control classrooms. During the last year, the research team anticipates testing *Math Snacks* in schools outside of the given partner districts, either in another state or in New Mexico, in order to answer the research question about usefulness in any school.

External Evaluation

The Wexford Institute will conduct an external evaluation of the project. In Years 1-4 the evaluation team will collect and analyze data to monitor project activities and to assess indicators of whether the project is progressing toward its goals and objectives and meeting its deliverables.

In Year 5, cumulative data will be used to determine if the project has met its goals, objectives and deliverables. Wexford will collect data via mid- and end of year surveys with staff and participants, to identify strengths, weaknesses, and areas of improvement. They will also collect data as evidence of progress, such as surveys, artifacts and project records. This information will be compiled in an annual report and shared with the project director and NSF,

Dissemination

Math Snacks materials will be integrated into a variety of math education professional development and school projects being undertaken by the College of Education's Institute for Mathematics and Science Education. They will also be used in the pre-service and masters teacher preparation programs. This includes promotion of the website in Institute materials and the development of publications for national journals based on findings from this research. Material will also be promoted at national math education conferences in years 4 and 5. Once developed, materials will be posted to a freely accessible website, to *Teacher Tube* and NMSU's *iTunes* portal.

Expertise and Responsibilities

Lead P.I. and Director of Research: Dr. Karin Wiburg

- Provide budgetary oversight
- Hold regular project management meetings
- Attend PI meetings as requested
- Oversee internal researchers
- Serve as lead author on all reports and articles published

Dr. Wiburg is currently the Associate Dean for Research in the College of Education. She is also a Professor of Learning Technologies and Curriculum. She continues to do research on the design and implementation of learning environments for education. She has been involved in education as a teacher, administrator and college professor for almost 40 years and is currently P.I. for the Mathematically-Connected Communities project. She has written four books and published numerous academic articles.

Co-P.I. and Director of Development: Dr. Barbara Chamberlin

- Oversee production of Math Snacks modules.
- Lead regular project design meeting.
- Serve as lead author on all design documents created

Dr. Chamberlin currently directs development in NMSU's Learning Games Lab, overseeing formative and predictive research on game characters, use and educational potential. Her PhD is in instructional technology, and her research emphases are in game development and interactive media. She has been developing educational games for 14 years including games on science and math concepts. Additionally, Dr. Chamberlin served as the lead developer on the pilot Math Snacks materials, covering development of games and animations for handheld computers or other mobile devices.

Co-P.I. and Director of Formative Testing: Dr. Jeanne Gleason

- Oversee all formative evaluation, securing formative test groups, collecting data.
- Oversee video development and publishing of all final resources.
- Compile formative data for analysis by development team.

Dr. Gleason serves as Director of Media Productions and the lead instructional designer on game and instruction activities, ensuring they meet national standards and measurable learning objectives. She has more than 30 years experiences working on multimedia educational tools and development, particularly for science and math instruction. Under Dr. Gleason's leadership, the NMSU team has produced more than 20 science and math education, food safety, nutrition and obesity games, touch screen public kiosks, Web sites, animations, videos and print publications in several different languages, including, Spanish, Navajo, Mandarin, Cantonese, Fijian and English. She has served as senior personnel on more than 50 funded grants to date.

Math Content Specialist: Dr. Ted Stanford

- Serve on design team guiding math content and pedagogical approach.
- Conduct formative evaluation in classrooms

Dr. Stanford is an associate professor for mathematics in the Department of Mathematical Sciences at New Mexico State University where his specialization is the study of topology. For the past five years, as part of the Mathematically-Connected Communities grant. He has worked extensively with colleagues in the College of Education, middle school math teachers, and middle school students. He was the math specialist for the Pilot Math Snacks Animations.

Research Team: Ken Korn, Dr. Alfred Valdez, Naomi Schmidt

- Design research and find best instruments
- Collect and analyze data
- Run statistical analysis including mixed effects models
- Compile and analyze all findings, make reports

Ken Korn served 33 years as the Director of Assessment, Strategic Management and Accountability first for the El Paso School District and later in the N.M. Gadsden Independent School District. He has since retired from public school work and has been teaching assessment and research at New Mexico State University while also serving on the research and evaluation team for several math projects in the Institute for Mathematics and Science Education. Dr. Alfred Valdez, Assistant Professor in Special Education is an experienced statistician and researcher in the area of learning with technology. Naomi Schmidt, has been an instructor in the department of Educational Statistics for the last 16 Years. She serves as a statistician for various grants across the college and assists doctoral students and faculty with research design.

External Evaluation and QA Committee Coordination: The Wexford Institute

- Conduct annual evaluation of project to analyze progress towards goals.
- Appoint members, establish protocol and compile data from Quality Assurance committee.

Wexford in a non-profit educational agency focusing on research and development, evaluation, quality assurance and strategic planning, and related professional development and technical assistance. Wexford staff have conducted scientifically-based research, design-based research and have evaluated STEM and other programs for thirty years, including similar recent projects. Wexford has expertise in carrying out these services for universities, school districts and regional agencies with diverse populations. Sheila Cassidy, the executive director of Wexford, has a background and expertise in research & evaluation, quality assurance, mathematics education, e-learning, professional development, and effective educational programs for English Learners.

Results from Prior NSF Support

Karin Wiburg is currently a Co-P.I. on the *Scaling Up Mathematics for Achievement* SUMA grant, which is in its second year. This project is researching how a model for building capacity for mathematics achievement based on previous work on the Gadsden Mathematics Initiative works in a larger and more diverse district. Dr. Wiburg previously worked as a researcher in the Gadsden Mathematics Initiative (GMI) and conducted a Student Outcomes Study that investigated how professional development in that project affected student achievement. The GMI recently ended but was a very successful NSF project, nominated as a Golden Nugget. Math scores of low-income, English-Language Learners in this district continue to outperform similar students in the state and in some grades (3^{rd} and 8^{th}) are higher than average scores for all students.