Math Snacks: Using innovative media to address conceptual gaps in mathematics understanding

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"Math Snacks" are clever, engaging and focused technology-based resources designed to help learners access in a unique way the concepts behind frequently misunderstood mathematics skills and knowledge. Based on research and thorough assessment of existing gaps in knowledge, the final tools are developed by math educators and mathematicians partnering with game developers and animators. Users of "Math Snacks" integrate technology (web, animation, video, iPhone and iPod) into their math curriculum by using developed tools as pre- and post- class activities, as part of a lecture and as resources for out-of-school learning. All completed materials are available for free at http://www.mathsnacks.org. Further support for students include supplemental materials and Web 2.0 portals (Facebook, Twitter, Blog).

The Math Snacks project addresses the problems middle grades students have learning mathematics by focusing on basic conceptual understandings of mathematics that are a foundation for further advanced learning. The concepts to be developed into innovative media are selected for two reasons: because the concept to be learned is a key to mathematical intellectual development and because it is also a concept that has been missed across a large number of students based on test and observational data. It is also likely to be a concept that the teacher finds difficult to teach. The following article suggests the need to refocus mathematics on core concepts, and to address first those concepts that are the most difficult for most students.

Research supports students learning core fundamental understandings of mathematics, a critical content area which students need to master in order to take advanced courses in the STEM field and eventually become knowledgeable citizens and workers in the 21st century. 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).

Mathematical content is stored in the mind as a concept image (Tall & Vinner, 1981) A concept image is defined as "the total cognitive structure that is associated with the concept, which includes all the mental pictures and associated properties and processes", while the concept definition is defined as "form of words used to specify that concept." For example, the formal definition of a fraction is "any number that can be put into the form $\frac{a}{b}$ (also sometimes written a/b), where a and b are numbers and b is not 0" (McKeague, 2008). A possible concept image of this definition would be the usual pie cut into four pieces. When you ask students to tell you a fraction they will think of certain numbers such as $\frac{1}{2}$ or $\frac{1}{3}$. The Math Snacks products, by using technology, can tap into multiple representations of a concept and provide another concept image to the student in order to deepen conceptual understanding. As Moreno & Mayer (2007) suggested, "Multimedia supports learning by providing additional graphical illustrations."

If U.S. students are to be more successful in life, 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), provides such a foundation to students. Other high-scoring countries, such as Japan, also have clear national systems that define what topics are to be covered and then cover them 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. Examples include the *Focal Points* proposed by the National Council for Teachers of Mathematics and the new National Common Core Standards. The *Math Snacks* project provides a key set of topics to be explored and understood within a developmental framework of conceptual understanding that moves from the 6th- 8th grade levels.

Initial Analysis of Gaps

An analysis of over 24,000 student scores in 3rd -8th grade in high-need NM districts showed consistent areas of weakness. 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 measure, they don't score well in a section of the New Mexico Standards Based Assessment that requires explanation their understanding of a concept like measurement. Overall, student scores were weak in demonstrating conceptual understanding in topics that include: number systems and operations, fractions and decimals; and moving between numerical, tabular, and graphical data describing linear relationships. The Math Snacks are being developed to address these topics along with the concept of variables.

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. (I would move this paragraph to explain validity of test to before the other paragraph in this section to show the testis valid)

The Potential of Media

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 to 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 manipulatives. 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 a modified LOGO environment to help students learn geometry. Interactions with media around mathematical topics have the potential to help students fill their conceptual gaps in understanding. As Atkinson (2005) states, "Creating multimedia presentations that encourage learners to build coherent mental representations enhances learning." (p. 404) These mental representations are exactly the concept images. Some concept images must be dynamic and interactive in order to fully understand the capabilities of concepts. For example, when talking about a number line, to have students actually go on a computer and zoom in and out of a number line would greatly enhance the concept image of infinite numbers between two chosen numbers and the strength of the tool that is a number line. Notice that in a classroom, a teacher without access to a computer projection image would have to draw numerous number lines to display the same message which would be time consuming and also would not support free exploration with a number line as an object. This scenario in the classroom is typical of a static concept image. Pilone & Pilone (2009) suggest "You can change the scale on your number line without affecting the values on that number line." Assisting middle school students with more concept images, like an expandable and contracting number line, will help students to be better prepared for algebra and move from number lines to a coordinate plane.

The *Math Snacks* grant researches and evaluates the potential of short animations and games in helping learners understand concepts before or after engaging in more formal classroom learning. The products are also meant to be used anywhere and at any time after school, at home or on the school bus. According to the cognitive theory of multimedia learning (CTML), combining spoken text with dynamic graphics should promote learning with understanding (Atkinson, 2005). 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. According to Robert Rubenstein (1994), students fourteen years of age or younger have a working memory with an attention span of 5-10 minutes, which correlates with the length of the time involved with watching or playing a Math Snack. The six resulting pilot animations are popular with students and teachers.

From Gaps to Goals to Math Snacks

Combining our knowledge of the gaps introduced above, along with an understanding of the potential of media in classrooms, the development team then created mathematical goals and objectives to guide the multimedia development of products for the first two years. These goals are influenced not only by the gaps analyzed, but from qualitative interviews with students and teachers, and from the extensive experience of educators on staff in teaching mathematics in schools. The first year goals concentrated on number sense, with multiple representations of numbers, the use of the number line as a tool, and solving situated problems using operations. The goals for next year are still being refined but include variables with an emphasis on why they are important and powerful in mathematics.

The development team also gives plenty of thought to the pedagogical usefulness of the product along with the mathematics involved. For example, learner and teacher guides are included with every Math Snack, and the development group decided that a two page guide would suffice since the guide's include inquiry questions and based more on conceptual learning than traditional math practice. The guides do provide application of the concepts as well as conceptual questioning; aiming at personalization such as "Can you give me an example of how this Math Snack applies to your life?" The guides also provide stimuli for further student exploration. One Math Snack , the Bad Date shows three scenarios- one in which the male talked almost all the time; one in which the female dominated the conversation and one in which their conversations can be coded as a desirable one-to-one ratio. At the end of the animation, the number of words spoken by the female and the male on the date was 57:56, until the male said "Bread!" A conceptual question that arose was "What if the male did not say 'Bread'? This asks students to examine when approximation and accuracy are important for using mathematics in everyday life.

Once the goals are settled on, the development team brainstorms products that would address some of the goals. In the brainstorming meeting, every product that is introduced for possible development must correspond to the agreed goals, which also reflect extensive research on the mathematics learning gaps. For example, one of our products in development is an interactive number line so that students can realize the potential of a number line and the expansiveness of real numbers. This product is linked to the goal of number sense and in particular the number line as a scalable tool. The use of technology makes possible exciting interaction with a movable number line. It is important because it brings to life the number line, which has been shown in textbooks or provided in lectures only as a stagnant image. A teacher in a classroom cannot draw on the board a dynamic magnification or expansion of a number line.

Each product is tested by the Learning Games Lab on campus, where students from local schools are invited to play or watch the product. A video closet is provided so students can walk into the closet at any time and report to a video camera what they did and did not enjoy. They are also asked to make suggestions for improving the games or animations. Then the products are used in pilot classrooms where project staff works with volunteer teachers to test the Math Snack in a classroom where more feedback is gathered. All products are tested multiple times through successive revisions and teachers are invited to suggest how the Math Snack can help them to teach concepts. Finally, a quality assurance group headed by external advisors met with the development team twice a year to give a more formal critique of the appropriateness and usefulness of the product prior to production.

Incorporating the Math Snacks with Teachers

Researchers (Hill, Rowan, & Ball, 2005) have found that teacher mathematics knowledge is positively related to student achievement. Many middle school teachers have 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 students via media.

In the summer of 2010, the math specialists working in the Math Snacks group were invited by the principal of Sunrise Elementary School to run a Math Snacks camp in their school. This principal then corresponded with the principal of Mesa Middle School to hand pick 8 teachers for the camp, and in turn each teacher picked 4 or 5 students from the school representing different demographics. The camp ran for 5 days, with two teachers taking 8 students and one math snack product as an area of focus from mathematics. The focus areas included: ratios, measurement, number line and scale factors. The model of the Math Snacks professional development was very innovative and had proven successful in previous grants with teachers. The teachers would spend time working with students to develop their ability to use technology to teach mathematics in the morning and then would use the afternoons to critique and modify what had happened with the students. A final project was done by the groups focused on the mathematics topic of the selected Math Snacks. For example, one group chose the snack “Number Rights”, an animation centered around people carrying number placards on a number line. The purpose was to help students recognize that numbers like -3.4 or ½ have actual places on the number lines. The students in the group chose a number on the number line, and built a house on their number. Each family member living in their house was a different numerical representation of their number. For example, if their number was $3\frac{2}{3}$, their mother was $3.\overline{6}$, while their father was $\frac{8}{3}$. Students also made up neighbors, or numbers that were living "close" to them. The group incorporated technology by setting up a website with separate pages for each student and their numerical family, and presented the website to their real family at the end of the camp. Many of these students presented their number family in both English and Spanish.

The students learned math by using the technology, however, it was the teachers who really learned the most mathematics. Prior to the summer academy they were not aware of many of their own misconceptions about math concepts. One example involved a teacher learning the difference between a ratio and a fraction. The students asked if a ratio could be written in the same way as a fraction. A ratio is defined as the comparison between two quantities. So if you compare 2 boys to 3 girls or 3 girls to 2 boys, the ratio is 2:3 or 3:2. But it depends on how you label the ratio. Similar exploratory questions were prevalent in the lesson plans of teachers for each of the mathematics topics.

The teachers loved the fact that they had ample time to cover one topic area of mathematics, and absolutely enjoyed the incorporation of technology, in particular, the *Math Snacks*. As the teachers debriefed their morning lessons with students they continued to learn and to suggest new ideas they wanted to add to their lessons. Two teachers emphasizing scale factor, wanted to add the fact of scaling down by 5 to scaling up by 1/5. These experiences enhanced the concept images of the teachers, which in turn will hopefully be passed on to the students they teach. Concept images are the key mathematical ideas that are easily retrievable in a student's mind, and we must strive to introduce as many as we can. Math Snacks aims towards that goal.

Conclusion

The Math Snacks project uses the results from the NMSBA which is aligned with the TIMMS international study to identify educational gaps in mathematics. These gaps assist the development team to create goals, which guide them to produce Math Snacks. Highly engaging, these snacks tap into the potential of multimedia learning. One by-product of this engagement would be that teachers understand the importance of a student's concept image. Hopefully Math Snacks will be able to provide students with another concept image that accurately portrays the important math concepts students need to be successful.

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